Report No. SR2010-06-02

2010 AirCare Program Review, Phase 1

prepared for:

TransLink

June 30, 2010

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Executive Summary

An analysis conducted by Sierra Research, Inc. (Sierra) and SENES Consultants Limited (SENES) indicates that continuation of the AirCare Vehicle Inspection and Maintenance (I/M) Program will provide significant reductions in vehicle emissions of unburned hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NOx). The economic value of the public health benefits is estimated to exceed the cost of continuing the program.

Although the replacement of older vehicles in the fleet with newer vehicles designed to meet more stringent emissions standards is reducing motor vehicle emissions, there is compelling evidence that most late-model vehicles eventually develop emissions-related defects. Data available from the State of California demonstrate that many of these defects go uncorrected in the absence of an effective I/M program, even for vehicles equipped with on-board diagnostic (OBD) systems. That is why California has recently decided to make a number of program enhancements and continue its I/M program for the indefinite future. Thirty-one other states, the District of Columbia, and the Province of Ontario also continue to operate I/M programs. Ontario has recently issued a Request for Proposals for a modified program to be operated until at least 2019.

Because the "potential to emit" for late-model vehicles is just as great as for older vehicles, the total tonnes of emissions reduced by requiring the repair of defective vehicles is as large in the future as it is currently. In fact, modified test procedures for better identifying evaporative emissions-related defects would provide a greater emissions reduction than is being achieved by the current AirCare Program.

The current AirCare Program reduces motor vehicle emissions of HC and NOx, the principal precursors of ozone and "secondary" particulates, by approximately 20%. As properly maintained vehicles approach zero emissions, the percentage reductions associated with the repair of defective vehicles increase to about 50% by 2020. When the emissions from industrial sources and vehicles not subject to the program (e.g., heavy duty trucks, marine vessels, aircraft) are included, the effect of continuing the AirCare Program on total emissions in 2020 is a 4.7% reduction in HC and an 8.8% reduction in NOx.

In addition to reducing common air contaminants, continuation of the AirCare Program is estimated to reduce greenhouse gas emissions from motor vehicles by 1.1% and toxic air contaminants (e.g., benzene) by over 40%.

With minor program changes, we estimate that a next generation of the AirCare program could reduce impact-weighted emissions[1] at a cost-effectiveness ratio of <$3,000/tonne, which is competitive with the cost-effectiveness ratio of other programs that have been imposed to control emissions from other sources.

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[1] HC + NOx + CO/7

Based on the analysis of air quality and health impacts performed by SENES, continuation of a modified AirCare program through 2020 is estimated to reduce lifetime cancer risk by 1.57%. There would also be significant benefits resulting from reduced public exposure to nitrogen dioxide (NO_2), secondary particulate, and CO. The projected reduction in ambient NO_2 and particulate concentrations is estimated to result in 140 fewer premature deaths during the 2011-2020 period and significant reductions in hospital admissions related to acute respiratory symptoms and heart disease.

The monetary benefits from the reduced health damage would be primarily related to a lower incidence of premature mortality. On an annual basis, the benefits are estimated at $77 million during the 2011 to 2020 period. In comparison, the annual cost of the proposed revised AirCare Program is estimated to average about $47 million over the same period of time. (For comparison purposes, continuation of the current program is estimated to provide $30 million in annual health benefits at average annual cost of $45 million.)

Economic impacts of the AirCare Program that have not been quantified include the reduced number of vehicles in operation with visibly smoking exhausts. The program also provides an estimated $35 million per year in revenue for the automotive repair industry. Because a significant number of failing vehicles are retired from service or sold outside of the area instead of being repaired, the program is also estimated to result in at least an additional $21 million per year in new vehicle sales. In addition to reducing emissions, this increase in fleet turnover contributes to increased vehicle safety and fuel economy.

2010 AIRCARE PROGRAM REVIEW, PHASE 1

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Glossary and Abbreviations

ASM	Acceleration Simulation Mode. A steady state, chassis dynamometer test during which the vehicle is loaded to simulate the power required to accelerate at 3.3 mph/s, which is the maximum acceleration rate of the Federal Test Procedure used to certify new passenger cars and light-duty trucks.
CAC	Common Air Contaminant. A pollutant that contributes to conventional air pollution problems, such as levels of ozone, carbon monoxide, or nitrogen dioxide in excess of health-based air quality standards.
CH_4	Methane (the principle component of natural gas). A single-carbon hydrocarbon molecule that does not significantly contribute to ozone formation but which is a greenhouse gas.
CNG	Compressed natural gas.
CO	Carbon monoxide. A product of incomplete combustion and a weak ozone precursor that is harmful to health at sufficiently high concentrations.
CO_2	Carbon dioxide. A non-toxic product of combustion that does not contribute to conventional air pollution but is a greenhouse gas.
Cost-effectiveness	The dollars spent per unit (e.g., tonne) of emissions reduced
DTC	Diagnostic Trouble Code. A code stored in a vehicle’s on-board diagnostic (OBD) system indicating a particular type of fault has occurred.

EGR	Exhaust Gas Recirculation. An emissions control technique used to reduce NOx emissions from internal combustion engines.
EPA	U.S. Environmental Protection Agency.
GHG	Greenhouse Gas. A gas that absorbs infrared radiation and contributes to global warming, including vehicle emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).
g/km	Grams (of emissions) per kilometer of travel.
g/mi	Grams (of emissions) per mile of travel.
GVRD	Greater Vancouver Regional District.
HC	Hydrocarbons. One of the products of incomplete combustion that contributes to ozone formation.
I/M	Inspection and maintenance.
IM147	A 147-second transient (stop-and-go) chassis dynamometer emissions test that is a shortened version of the Federal Test Procedure.
IM240	A 240-second transient (stop-and-go) chassis dynamometer emissions test that is a shortened version of the Federal Test Procedure.
LDT	Light-Duty Truck. A truck with a gross vehicle weight rating of 8,500 pounds or less.
LFV	Lower Fraser Valley. The region in British Columbia used for emission inventory and airshed modeling by Metro Vancouver that extends approximately from the western edge of Bowen Island east to beyond Hope and from the Canada-U.S. border north to beyond Lions Bay.
LPG	Liquified Petroleum Gas. A byproduct of natural gas production and oil refining consisting primarily of propane and smaller amounts of other light hydrocarbons (e.g., butane).
MIL	Malfunction Indicator Light. A dashboard warning light, sometimes called a “check engine light,” which is illuminated when a fault has been detected by a vehicle’s on-board diagnostic system.
MOBILE6.2	A computer model developed by the U.S. Environmental Protection Agency to estimate emissions from motor vehicles and the effect of I/M on motor vehicle emissions.

NO	Nitric oxide. An ozone precursor and product of high temperature combustion emitted by internal combustion engines.
N_2O	Nitrous oxide. A greenhouse gas emitted by combustion engines in trace amounts.
NO_2	Nitrogen dioxide. An air pollutant directly emitted by internal combustion engines and formed in the atmosphere from nitric oxide.
NOx	Oxides of nitrogen (either nitric oxide or nitrogen dioxide or a mixture of both). An ozone precursor and product of high temperature combustion emitted by internal combustion engines.
O_3	Ozone. A respiratory system irritant formed from reactions between hydrocarbons and nitrogen dioxide in the presence of sunlight.
OBD	Onboard diagnostic system. An onboard computer used to monitor emissions control system performance.
OBDII	A second-generation OBD system used on 1998 and later models.
PM	Particulate matter. Airborne particles either emitted from sources of air pollution or formed in the atmosphere.
PM_{10}	Particulate matter of an aerometric diameter equal to 10 microns or less.
$PM_{2.5}$	Particulate matter of an aerometric diameter equal to 2.5 microns or less.
ppm	Parts per million.
Tonne	Metric tonne. 1,000 kilograms.
U.S.	United States of America.
US$	Currency in United States dollars.
VOC	Volatile Organic Compound. Often used interchangeably with "hydrocarbons." Technically, VOCs are hydrocarbons that vaporize at standard temperature and pressure. However, when used by air pollution control agencies, the term usually excludes relatively non-reactive molecules, such as methane and ethane.

1. Introduction

1.1 Background

Since motor vehicles had been identified as a major source of carbon monoxide (CO) and ozone precursors, the Greater Vancouver Metropolitan District issued a Request for Proposals in 1990 for assistance in designing and implementing an I/M program to deal with unhealthful levels of CO and ozone in the region. Based on its experience in designing and evaluating I/M programs operating in other areas, Sierra was the contractor selected.

AirCare I – Working with the local I/M Implementation Task Force, Sierra designed the first generation of the AirCare program, prepared a Request for Proposals for construction and operation of the proposed network of inspection stations, and assisted in the contractor selection process during work performed in 1990 and 1991. The program design specified annual testing using the Acceleration Simulation Mode (ASM) dynamometer test procedure, visual inspections for certain types of defects difficult to identify with an exhaust emissions test (e.g., a missing gas cap), preferential treatment for vehicles that are repaired by "certified" mechanics, and continuous monitoring of mechanic performance leading to elimination of certified mechanics with unacceptable performance. This first generation program was conducted from September 1, 1992 through August 31, 1999.

AirCare II – In September of 1997, two years before the end of the first contract, Sierra and its subcontractor Levelton Associates were retained to conduct a review of the program and develop recommendations for program improvements. Sierra recommended a number of program changes, including (1) replacing the ASM steady-state dynamometer test with the more effect IM147 transient dynamometer test[2] (which measures emissions under conditions more representative of stop-and-go driving); (2) replacing exhaust emissions testing with OBD system testing for 1998 and subsequent model year vehicles to simultaneously increase the effectiveness and reduce the cost of testing newer vehicles; (3) replacing underhood inspections with a functional test of the gas cap; (4) using more stringent criteria for granting waivers to vehicles repaired at certified repair stations;[3] (5) reducing inspection frequency from annual to biennial for vehicles that pass an initial inspection; and (6) exempting new vehicles from inspections for their first two years.

Although the recommended IM147 test requires more expensive equipment, Sierra's analysis indicated that less frequent, biennial inspections could be used for passing vehicles, thereby preventing an increase total program cost while still achieving greater emissions reductions.

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[2] The IM147 is the second phase of the longer IM240 test that was eventually adopted.

[3] A minimum expenditure on repairs was recommended before granting waivers to vehicles with extremely high exhaust emissions when returning for re-inspection.

Some of Sierra's recommendations were not accepted and others were modified. In order to minimize testing time, the decision was made to retain ASM testing for pre-1992 model vehicles. IM240 testing, rather than IM147 testing, was chosen for 1992 and later models. Because of uncertainties regarding the effectiveness of making pass/fail decisions based only on OBD testing, both OBD testing and IM240 testing was chosen for 1998 and newer models. Rather than switching to biennial testing only for vehicles that pass the initial test, the decision was made to use biennial testing for all 1992 and newer vehicles while retaining annual inspection frequency for pre-1992 vehicles that continue to be tested using the ASM procedure.

Under a subsequent support contract issued in 1999, Sierra prepared a Request for Expressions of Interest (REOI) to potential I/M contractors and assisted in the review of responses to the REOI. Sierra then drafted a detailed Request for Proposals (RFP) for the rebid of the I/M contract. A contract for the operation of AirCare II was negotiated with Envirotest Canada. Effective January 1, 2004, the exemption for new vehicles was extended from two years to three years and, finally, to four years in January 2006.

<u>AirCare III</u> – With the expiration date of the contract for operating AirCare II approaching, another review of the program was commissioned to evaluate the performance and cost effectiveness of the program, to recommend whether the program should be continued and, if continued, which options to improve the program should be given detailed consideration. Levelton Associates, Sierra's subcontractor during the previous review of the original AirCare program, was selected to perform the "Phase 1" review of AirCare II.

Levelton's November 2004 report pointed out that the cost-effectiveness of the program could be improved with no significant loss in benefits by deleting the IM240 test for 1998 and newer vehicles and making pass/fail decisions based only on the OBD test (which was the recommendation made by Sierra six years earlier). Levelton also pointed out that additional benefits could be achieved by requiring tailpipe testing of any vehicles with a "not ready" OBD monitor. In addition, Levelton recommended consideration of a longer exemption period for new vehicles, a test for liquid fuel leaks on older vehicles, and the use of self-service kiosks for OBD testing as an alternative to having the inspection performed in a centralized test facility on 1998 and newer models.

Following the Phase 1 study by Levelton, Sierra was retained to perform a detailed evaluation of potential program changes. In August of 2005, the Phase 2 study conducted by Sierra provided a detailed proposal for the next generation of the program, including its scope, economic feasibility, delivery model, transitional arrangements, user fees, and other design elements. A comprehensive feasibility analysis was also completed in which the potential new program and various associated details were examined from a variety of views, including technical, environmental, economic, and customer acceptability perspectives.

Sierra agreed with the recommendations of Levelton's Phase 1 study with respect to the following two program changes:

1. For 1998 and newer models, making the initial pass/fail decision based only on a check of the OBD system.

2. Expanding the exemption of new vehicles to include the five newest model years for most vehicles to reduce program costs and improve consumer convenience without compromising program effectiveness.

With respect to the OBD testing recommendation, it should be noted that Sierra also recommended that "a single criterion of one allowed unset monitor be adopted for all 1998 and newer vehicles that are OBD tested." It was also recommended that "Vehicles that do not have an illuminated MIL and do not meet the readiness criteria would be subjected to a backup IM240 tailpipe test and gas cap integrity check."

The option of self-serve kiosks proposed for consideration in the Phase 1 study was determined to be of uncertain feasibility and effectiveness within the lead time available for development and implementation.

As had been suggested previously, during Sierra's 1998 review of the first generation AirCare program, replacing the IM240 test with the shorter IM147 test was noted as an option that would slightly reduce test time in exchange for an up-front cost for reprogramming. No change was recommended with respect to ASM testing for pre-1992 models. (Although not documented in Sierra's report, the greater feasibility of retaining annual inspections for older vehicles was a factor in this recommendation; IM240 testing would have increased the cost per test and made it more difficult to retain the value of annual inspections for older vehicles.)

1.2 Purpose and Scope of the Study

As stated in the Request for Proposals issued by TransLink in November of 2009, the purpose of the AirCare Program Review was "to perform an analysis of projected air quality and health benefits that could be obtained from a vehicle emissions inspection and maintenance program in the period 2012-2020, beyond the expiry date of the current service delivery contract on December 31, 2011." Under Phase 1 of the project, the following eight specific tasks were identified:

1. Development of an Evaluation Framework;
2. Overview of Air Quality in the Study Area;
3. Review of Emissions From Light-Duty Vehicles;
4. Review Trends in Emissions Control Technologies;
5. Review Trends in I/M Testing Programs and Procedures;
6. Review of Emissions from Other Sources and Associated Reduction Measures;

7. Develop a Decision Table for the Possible Recommendations; and
8. Provide Recommendations for Actions.

Following a brief description in Section 2 of the Evaluation Framework, the work performed under the other seven tasks is described in subsequent sections of the report.

Section 3 provides an overview of air quality and emissions in the Lower Fraser Valley.

Section 4 summarizes trends in vehicle emissions control technology and fuels with a focus on how these trends relate to emissions from the motor vehicle fleet and the effectiveness of vehicle I/M programs.

Section 5 provides a more detailed analysis of how the emissions control technology trends described in Section 4 are affecting emissions from vehicles as they age in the absence of an I/M program and with some type of I/M program assumed. In this section, the projected frequency of emissions-related defects occurring in advanced technology vehicles based on the MOBILE model is compared with the actual frequency of emissions-related defects observed during the inspection of vehicles selected at random at roadblocks set up by the California Highway Patrol. Estimates of the cost per tonne of emissions reductions achieved by the current AirCare program are also provided.

Section 6 summarizes the status of all I/M programs operating in North America and describes current and possible future trends in I/M testing.

Section 7 describes possible modifications to the current AirCare program and the effect they would have on the effectiveness and cost-effectiveness of the program. It also includes a description of how the cost-effectiveness of continuing the AirCare program compares to other potential control measures.

Section 8 describes the air quality and health benefits associated with continuation of the AirCare program based on the benefit estimates for both the current program and a possible modified program.

Section 9 contains a summary of the work performed and the recommendations of the study team.

Appendices to the report contain a summary of vehicle emissions standards, a detailed analysis of alternative fuels, and detailed emissions modeling results performed during the course of the study.

2. Evaluation Framework

In reviewing the future of the AirCare program, the parameters of greatest importance are the difference in future motor vehicle emissions associated with whether the AirCare program will be continued in some form and the associated change in air quality levels. Based on the projected change in emissions and air quality level, the threshold question will be whether there will be an economic benefit from the emissions reductions associated with continuing the program. If there is an economic benefit associated with the emission reductions the program can provide, the next question that needs to be answered is whether there are alternatives to continuing the program that can accomplish the same benefit at lower cost.

Under the first task of the Program Review, the evaluation framework illustrated in Table 1 was developed. As illustrated in the table, the evaluation parameters considered are in three general categories: environmental, economic, and a category we called "program effectiveness." The framework is designed so that the effect on each of these categories would be evaluated for three alternative scenarios:

1. No I/M program after December 31, 2011;

2. Retaining the current I/M program design, policies, and standards from January 1, 2012 to December 31, 2020; and

3. Implementing a new, revised I/M program with the best possible combination of low delivery cost and maximum yield of emissions reductions

<u>Environmental Parameters</u> – Under the environmental category, we addressed common air contaminants (CAC), greenhouse gas (GHG) emissions, toxic air contaminants, and air quality. The CACs we evaluated included unburned hydrocarbons (HC), CO, oxides of nitrogen (NOx) and particulate matter (PM). The GHG emissions included carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The toxic air contaminants included benzene: 1,3-butadiene; acetaldehyde; and formaldehyde. The air quality impact estimates were focused on ozone, nitrogen dioxide (NO_2), and PM.

An important element of the approach used to assess the CAC emissions impact of the alternative scenarios is that it did not rely exclusively on the current version of the MOBILE6.2C vehicle emissions model. As described in detail later, the current version of MOBILE forecasts emissions for future vehicles in the absence of an I/M program based on estimates made about 10 years ago, before any data were available on the actual performance of vehicles certified to meet stringent Tier 1 and Tier 2 emission standards at high mileage. The MOBILE model is based on the assumption that such vehicles will perform much better in customer service than older technology vehicles. Specifically, the current model assumes that Tier 1 and Tier 2 vehicles with emissions-related defects will have significantly lower emissions than older technology vehicles with the same defects.

Table 1
Evaluation Framework

Evaluation Parameters	Approach	Benchmark(s)
Environmental		
CAC[*] Emissions Reductions	Determine effect of alternative scenarios using MOBILE6.2C *and* updated estimates of Tier 1 and 2 vehicle emissions with and without I/M.	No I/M Program
GHG[**] Emissions Reductions		
Toxic Emissions Reductions		
Air Quality Impact	Determine emissions vs. air quality relationship from historical inventory and air quality data.	
Economic		
Impact-Weighted Cost/Effectiveness Ratio	Calculate total program costs and divide by impact-weighted emissions reductions.	Other Emissions Control Measures
Cost Per Vehicle	Calculate average cost per vehicle by vehicle age.	No I/M Program and the Overall Annual Cost of Vehicle Ownership
Total Program Cost	Calculate total costs from combination of inspection and repair costs for current and alternative future programs.	No I/M Program
Economic Benefit of Improved Air Quality	Use damage functions in referenced studies to estimate the value of estimate air quality benefit.	No I/M Program
Ancillary Benefits	Identify characteristics of the vehicle fleet other than emissions that are affected by program (e.g., noise, visible emissions).	No-I/M Conditions
Program Effectiveness		
Customer Convenience and Time Required	Use program data with other estimates to indicate total customer time required.	No I/M Program and Other I/M Programs
Relative Performance	Determine fraction of theoretical benefits achieved.	No I/M Program and Other I/M Programs
Consistency with Air Quality Plan	Compare program benefits to plan goals and objectives.	No I/M Program

[*] CAC = common air contaminant
[**] GHG = greenhouse gas

In addition, the model assumes a certain level of voluntary owner response to defects in Tier 1 and Tier 2 vehicles that are identified by the OBD systems installed on such vehicles. As described in detail later, revised estimates of vehicle emissions in the absence of an I/M program were developed from roadside inspections conducted in the State of California.

Because the use of photochemical modeling was beyond the scope of the study, air quality impacts of the three scenarios were analyzed using the Reduced Form Source-Receptor Tool (ReFSoRT), a screening-level spreadsheet tool that uses source-receptor relationships to determine changes in ambient concentrations of common air contaminants resulting from changes in emissions over a specified time period. The benchmark scenario for evaluating the environmental parameters was based on the assumption that the current program would be discontinued after December 31, 2011.

Economic Parameters – Under the economic category, we estimated the "impact-weighted" cost-effectiveness ratio of the reductions in CACs associated with continuation of an I/M program, the per-vehicle cost of continuing an I/M program, the total I/M program cost, and the economic benefit associated with the improvement in air quality provided by the continuation of an I/M program. We also addressed the ancillary benefits associated with continuation of an I/M program related to the reduced number of smoking vehicles and vehicles with defective exhaust systems that would otherwise be in operation.

The benchmark scenario for evaluating per-vehicle cost, total program cost, and ancillary benefits was based on the assumption that the current program would be discontinued after December 31, 2011. To provide perspective, a second benchmark for the per-vehicle cost calculation was an estimate of the average total cost of vehicle ownership. Finally, the benchmark for the impact-weighted cost-effectiveness of I/M was the impact-weighted cost of other air pollution control measures that have been adopted or considered for adoption throughout the U.S. and Canada.

Program Effectiveness Parameters – Under the program effectiveness category, we evaluated "customer convenience and time required" for the continuation of an I/M program compared to both the no-I/M scenario and compared to other I/M programs operating in North America. "Relative performance" for current and proposed alternative programs were also compared to other I/M programs operating in North America. In the category of "consistency with air quality plan," we compared the emissions reductions achievable under the three scenarios to the benefits assumed in Metro Vancouver's current air quality plan.

3. Air Quality and Emissions in the Lower Fraser Valley

3.1 Metro Vancouver Air Quality Management Plan

In 1990, the Greater Vancouver Regional District's Board of Directors called for the development and implementation of the first comprehensive Air Quality Management Plan (AQMP). The AQMP developed in 1994 had an initial objective of reducing total emissions of five major contaminants (i.e., carbon monoxide, sulphur and nitrogen oxides, volatile organic compounds, and particulate matter) by 50% by the year 2000.[4] This objective was subsequently revised to a 38% reduction in emissions from 1985 levels, and it was estimated that the combined emissions of these five contaminants had been reduced by 36% in the year 1999.[5]

The updated AQMP issued in 2005 established an overall vision for the region of providing clean and healthy air for current and future generations, and identified the following three goals:

1. Minimize the risk to public health from air pollution;
2. Improve visibility; and,
3. Minimize Greater Vancouver's contribution to global climate change.

In order to achieve these goals, the AQMP identified three strategies that are intended to help in achieving these goals:

- Reduce emissions from, major regional sources;
- Develop and implement local air quality management programs; and,
- Enhance air quality information and public awareness.

A total of 33 actions were associated with these strategies. Action item #3 in the 2005 AQMP was specifically directed at reducing emissions from on-road light duty vehicles. It stated that the GVRD would seek to continue emission inspection and maintenance programs (i.e., AirCare) that effectively reduce emissions from light- and heavy-duty vehicles. Together with the provincial government, the Greater Vancouver Transportation Authority, and the Fraser Valley Regional District, the GVRD would help to design and implement more effective and user-friendly emissions inspection and maintenance programs for the most polluting light and heavy-duty vehicles. In

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[4] Greater Vancouver Regional District 1994. GVRD Air Quality Management Plan. Burnaby, BC

[5] The Sheltair Group Resource Consultants Inc. 2001. Phase 2 Final Report: Harmonized Measures for Reducing Greenhouse Gases and Air Pollution in the LFV. Report prepared for the Greater Vancouver Regional District, Burnaby, BC, in association with Alchemy Consulting Inc., Constable Associates Consulting Inc, and The Delphi Group.

conjunction with other partners, the GVRD would also put more emphasis on Diesel emissions, as Diesel vehicles were anticipated to increase in popularity.

Metro Vancouver has also adopted a Sustainability Framework, which includes strategies and priority goals for both air quality and climate change mitigation targets. The Framework calls for a reduction in regional GHG emissions by 15% by 2015 and by 33% by 2020.

3.2 Air Quality Trends in the LFV

The 2005 AQMP adopted the following performance measures to monitor progress in achieving the goals of the AQMP over the period 2005-2015:

Goal A - Minimize the risk to public health from air pollution

- Reduce regional ambient inhalable particulate matter (PM_{10}), fine particulate matter ($PM_{2.5}$) and ground-level ozone levels
- Reduce emissions of PM_{10}, $PM_{2.5}$, and precursors to PM_{10}, $PM_{2.5}$, and ozone formation
- Improve local air quality

Goal B - Improve visibility

- Reduce regional ambient $PM_{2.5}$ levels
- Reduce emissions of $PM_{2.5}$ and its precursors

Goal C - Minimize Greater Vancouver's contribution to global climate Change

- Reduce regional greenhouse gas emissions

The AQMP did not establish specific numerical targets for reductions in the levels of either particulate matter, ozone, or greenhouse gases. Rather, the goals were defined under the concept of continuous improvement and keeping clean areas clean as defined within the Canada-Wide Standards (CWS) for particulate matter and ozone.

Information gathered from the LFV Air Quality Monitoring Network is used to support and guide Metro Vancouver's Air Quality Management Plan (AQMP) for the region. The network consists of 27 stations operated by Metro Vancouver and the Fraser Valley Regional District. The station locations are depicted in Figure 1 and identified in Table 2. Six of those stations (T12, T20, T27, T29, T30, and T33) are also part of the National Air Pollution Surveillance (NAPS) Network operated across Canada by Environment Canada.

Figure 1
Lower Fraser Valley Air Quality Monitoring Network

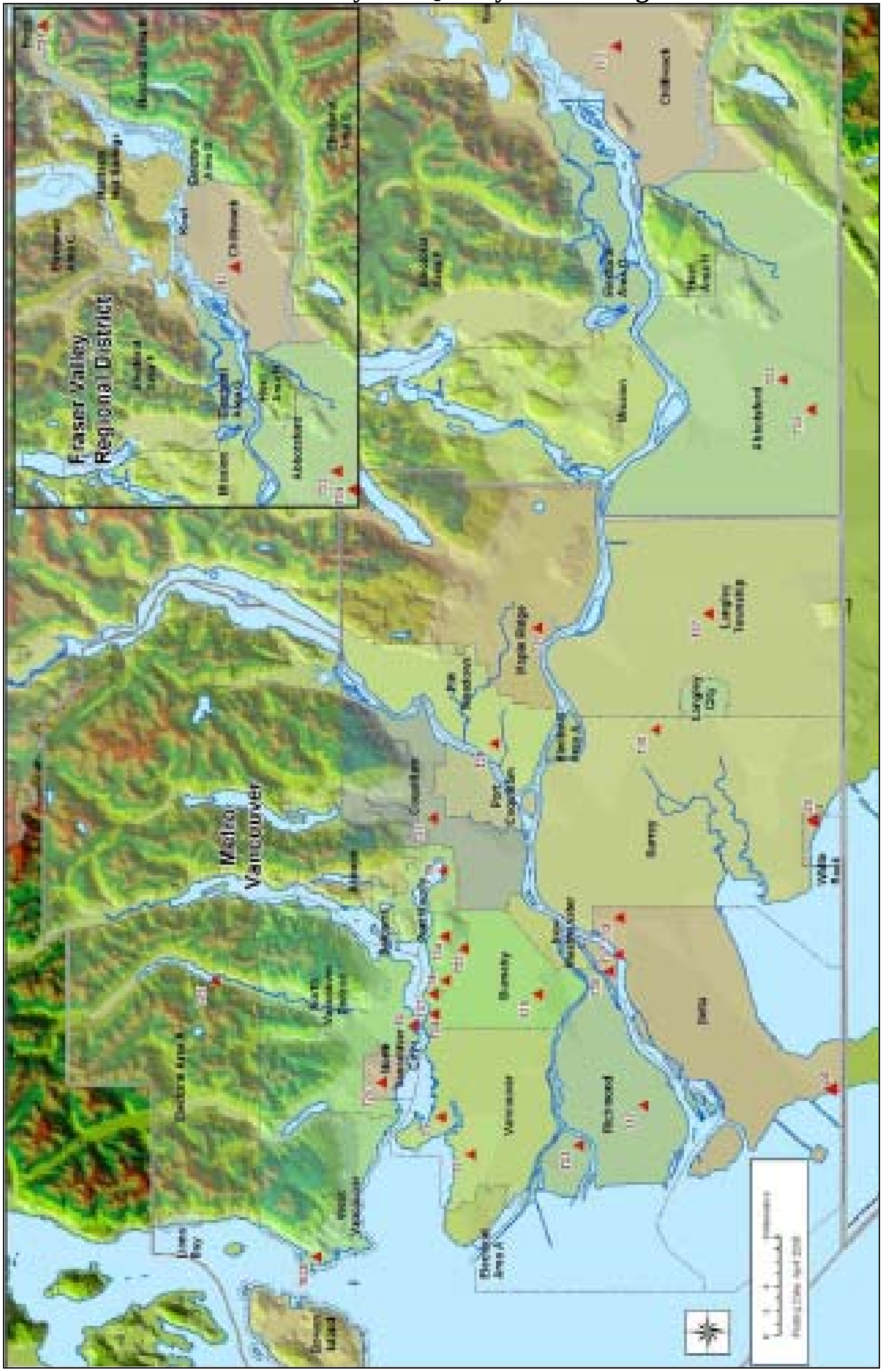

Table 2
LFV Air Quality Monitoring Network

Stations		Air Quality Monitors											
		Continuous									Non-Continuous		
		Gases							Particulate Matter				
ID	**Name**	**SO_2**	**TRS**	**NO_2**	**CO**	**O_3**	**THC**	**NH_3**	**PM_{10}**	**$PM_{2.5}$**	**VOC**	**SP**	**D**
T1	Downtown Vancouver	√		√	√	√					√		
T2	Kitsilano	√		√	√	√			√	√			
T4	Kensington Park	√	√	√	√	√			√	√			
T6	Second Narrows	√		√	√	√				√			
T9	Port Moody	√	√	√	√	√			√	√	√		√
T12	Chilliwack	√		√	√	√		√	√	√	√		
T13	North Delta			√		√							
T14	Burnaby Mountain			√		√							
T15	Surrey East			√	√	√			√		√		
T17	Richmond South	√		√	√	√			√		√		
T18	Burnaby South	√		√	√	√			√	√	√	√	√
T20	Pitt Meadows	√		√	√	√			√	√			
T22	Burmount		√				√				√		
T23	Capitol Hill	√	√										
T24	Burnaby North	√	√				√				√		
T25	Seymour Falls (S)					√							
T26	Mahon Park	√		√	√	√			√				
T27	Langley	√		√	√	√		√	√	√	√		
T29	Hope Airport			√	√	√			√	√			
T30	Maple Ridge			√	√	√							
T31	Vancouver Airport	√		√	√	√			√	√			
T32	Coquitlam			√	√	√							
T33	Abbotsford	√		√	√	√		√	√				
T34	Abbotsford Airport	√		√		√		√		√	√	√	√
T35	Horseshoe Bay				√					√			
20	White Rock												√
24	English Bay												√

SO_2 = sulphur dioxide; TRS = total reduced sulphur; NO_2 = nitrogen dioxide; CO = carbon monoxide; O_3 = ozone; THC = total hydrocarbon; NH_3 = ammonia; PM_{10} = inhalable particulate matter; $PM_{2.5}$ = fine particulate matter; VOC = volatile organic compounds; SP = particulate speciation; D = dichotomous particulate (PM_{10}/$PM_{2.5}$); (S) = seasonal; √ = monitored at this location

The following sections provide a discussion of the trends in ambient air quality that have been observed in the LFV since 1986, with an emphasis on changes in ambient concentrations of PM_{10}, $PM_{2.5}$, and ozone, as these are the key contaminants targeted for reduction in the 2005 AQMP.

<u>3.2.1 Particulate Matter</u> – Suspended PM can originate from natural sources such as dust disturbed by the action of wind, and from anthropogenic sources, such as the combustion of fuels. Fuel combustion tends to produce smaller PM, whereas dust tends to be of a larger size fraction. PM can remain suspended in air for as little as a few seconds to as long as several days or even weeks and longer. Precipitation tends to effectively remove PM from the air. Ambient PM is measured as both inhalable particulate matter, which is

the fraction of suspended particles with diameters of 10 micrometres (µm) or less and fine particulate matter, which have diameters of 2.5 µm or less. These fractions are denoted as PM_{10} and $PM_{2.5,}$ respectively.

There is significant interest in community levels of $PM_{2.5}$, as health research has indicated the smaller size range of suspended particles can have negative effects on human health at concentrations typically observed in urban areas. Exposure to $PM_{2.5}$ can aggravate pulmonary and cardiovascular disease, increase the occurrence of asthmatic attacks, and increase the risk of premature mortality. An additional adverse effect that can be related to ambient PM concentrations is the reduction of visibility. For this reason, $PM_{2.5}$ is one of two common air contaminants (along with ground level ozone) with Canada-Wide Standards. Metro Vancouver has adopted ambient air quality objectives of 50 $\mu g/m^3$ (24-hour average) and 20 $\mu g/m^3$ (annual average) for PM_{10}, and 25 $\mu g/m^3$ (24-hour average) and 12 $\mu g/m^3$ (annual average) for $PM_{2.5}$.

The progress report on the 2005 AQMP that was prepared in 2008[6] noted that PM_{10} concentrations had decreased slightly since 1994. Despite some year-to-year variability, peak 24-hour average PM_{10} levels had remained relatively constant in recent years. A comprehensive review[7] of the LFV Air Quality Monitoring Network in 2008 noted that there was little evidence of any change in PM_{10} concentrations since the early 1990s at monitoring stations in Kitsilano, Port Moody, Richmond, Pitt Meadows, Abbotsford, Chilliwack, or Hope.

Figure 2 shows the peak 24-hour average and the average annual PM_{10} concentrations for the six NAPS monitoring stations in the LFV over the period 1994-2006. The data indicate a high degree of year-to-year variability in peak concentrations. However, there has been a gradual trend to lower annual average concentrations, from 17 $\mu g/m^3$ in 1995 to 14 $\mu g/m^3$ in 2006, a decrease of 17.7%. Therefore, while the peak 24-hour average PM_{10} concentrations occasionally exceed the ambient air quality objective of 50 $\mu g/m^3$ at NAPS stations in the LFV, the annual average objective of 20 $\mu g/m^3$ is achieved.

The available monitoring record for fine particulate matter in the LFV is somewhat shorter than for PM_{10} levels. However, analysis of the data shows similar trends to PM_{10} in that $PM_{2.5}$ concentrations have been relatively constant in recent years, with some year-to-year variability. Trend analyses conducted for the network review in 2008 reported little change in $PM_{2.5}$ concentrations in Pitt Meadows, Chilliwack, or Hope, but did note some elevated readings during evening hours in Kitsilano.

Figure 3 shows the pattern of $PM_{2.5}$ concentrations averaged over the six NAPS stations in the LFV from 1999 to 2006. The figure indicates that peak concentrations were higher

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[6] Metro Vancouver 2008. Progress Report Air Quality Management Plan – October 2008.

[7] RWDI Air Inc. 2008. Review of the Lower Fraser Valley Ambient Air Quality Monitoring Network. Prepared for Metro Vancouver, in association with Sonoma Technology Inc., D.G. Steyn, C. Reuten and Bruce Ainslie.

Figure 2
Trends in PM_{10} Concentrations at NAPS Stations in the LFV

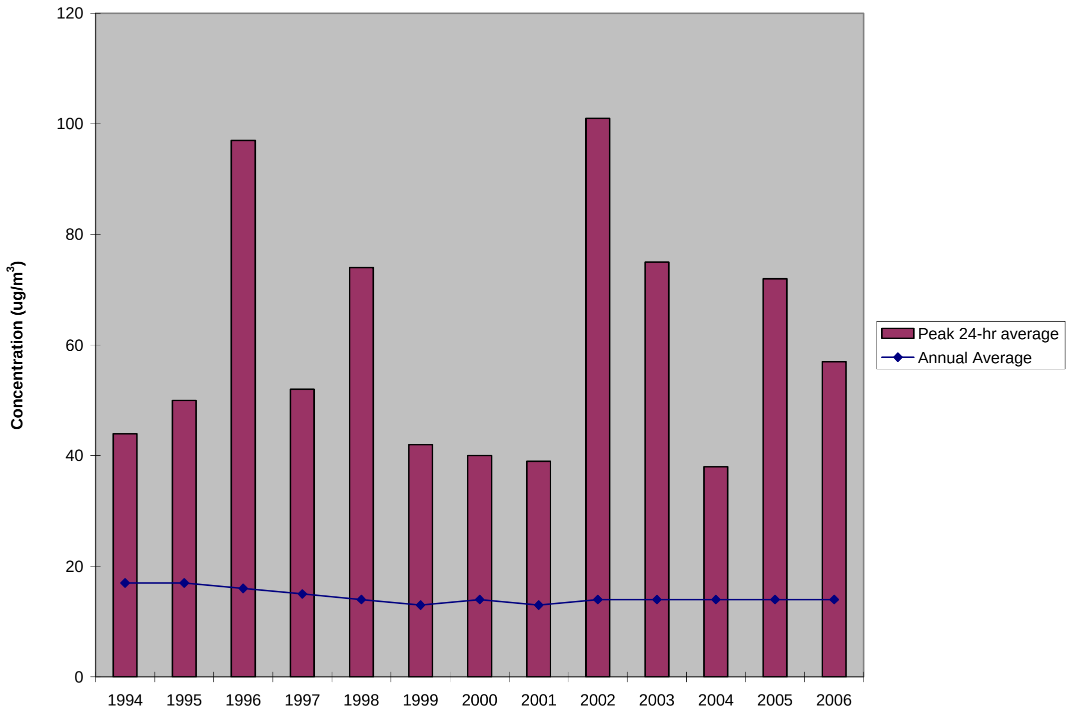
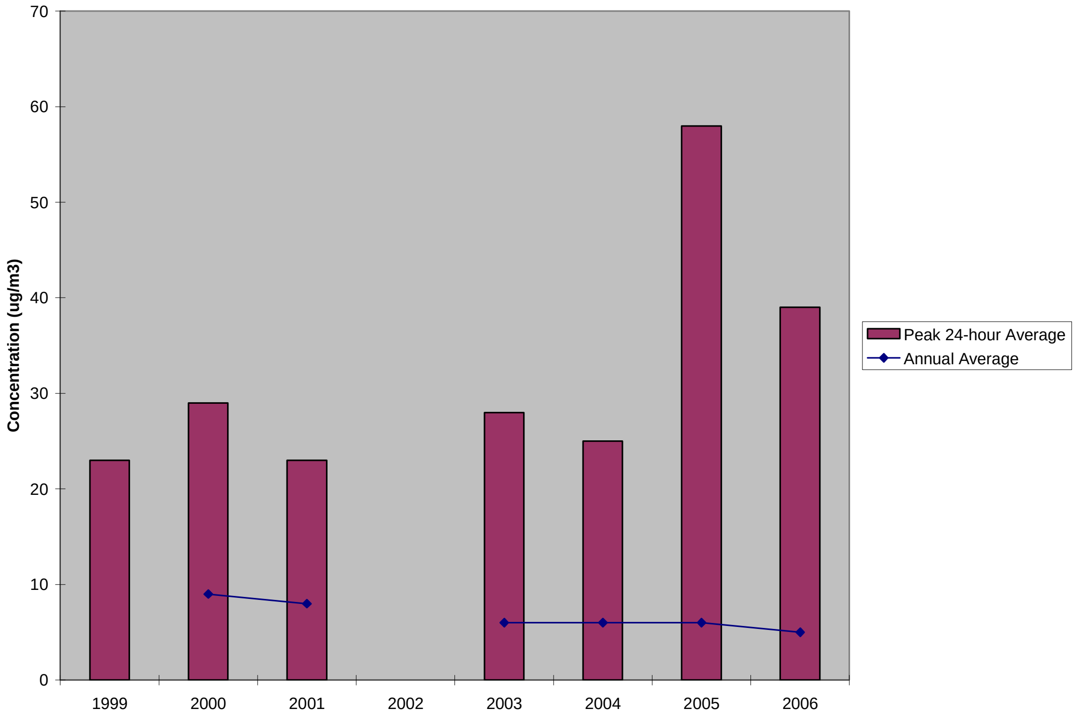


Figure 3
Trends in $PM_{2.5}$ Concentrations at NAPS Stations in the LFV



in both 2005 and 2006 than in previous years, but that there has been a trend to lower annual average concentrations from 9 µg/m^3 in 1999 to 5 µg/m^3 in 2006, representing a 44% decline in average concentrations. Therefore, while peak 24-hour average $PM_{2.5}$ concentrations continue to exceed the ambient air quality objective of 25 µg/m^3, the objective for annual average levels of 12 µg/m^3 is being achieved at the NAPS stations.

However, an analysis of the trends in $PM_{2.5}$ concentrations conducted by Statistics Canada across 15 monitoring stations in the LFV concluded that there had been no statistically significant change in $PM_{2.5}$ levels in the LFV over the period 1990-2005.[8] The analysis did not consider trends at individual stations; rather, it used air quality indicators that are designed to reflect longer term potential health impacts attributed to $PM_{2.5}$ (or ozone) concentrations. The air quality indicators are population-weighted and reported with the assumption that ground-level ozone and $PM_{2.5}$ concentrations are homogeneous within a radius of 40 km of each monitoring station.

Despite the lack of overt evidence for reductions in ambient concentrations of particulate matter, the progress report on the 2005 AQMP (Metro Vancouver 2008, op. cit.) concluded that efforts to improve regional ambient levels of particulate matter should continue because of the evidence from research on the human health effects of air pollution which indicates that fine particulate matter is harmful even at low concentration levels. In addition, it was noted that regional visibility can be impeded at the current particulate levels observed in the LFV. Efforts to reduce Diesel particulate matter emissions were identified as a particular priority for Metro Vancouver.

3.2.2 Ground-level Ozone – Ozone is a photochemical oxidant that is formed in the atmosphere from chemical reactions involving NOx, ultraviolet radiation (sunlight), oxygen, and HC. Ozone is a natural component of the atmosphere, with peak concentrations experienced in the lower stratosphere. In the lower troposphere, ground level zone (O_3) is a secondary pollutant and can be formed at considerable distances from the origin(s) of the primary pollutants. Relatively high ground level concentrations can be caused by anthropogenic emissions of NOx and HC, or by natural processes, such as stratospheric intrusion. Stratospheric intrusion involves atmospheric motions that bring ozone-rich air from very high altitudes to the surface.

Variations in weather patterns from year to year can have a large effect on community concentrations of ground level ozone. Currently, it is believed that springtime weather conditions favour the potential for stratospheric intrusion. Higher temperatures and solar insolation in the summer favour production of ozone from NOx and HC released in urban areas. The formation of ozone depends on a rather complex set of reactions that are sensitive to relative concentrations of pollutant precursors.

Metro Vancouver has adopted an 8-hour average ambient air quality objective of 65 ppb (126 µg/m^3), which is numerically identical to the CWS, except that the CWS is less

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[8] Statistics Canada 2007. Canadian Environmental Sustainability Indicators: Air Quality Indicators: Data Sources and Methods. Ottawa, Ontario. Catalogue No. 16-254-x.

stringent since it is applied as the 4th highest measurement annually, averaged over three consecutive years.

Much of the early efforts in the 1980s to reduce smog in the LFV were directed at short-term, peak ground-level ozone concentrations, and those efforts were successful. As indicated in Figure 4, peak ozone concentrations at the six NAPS monitoring stations were highest in the early 1980s, with a peak hourly averaged concentration of 250 ppb (500 µg/m^3) in 1980. Between 2000 and 2006, the peak hourly averaged ozone levels ranged from 69 to 82 ppb (124 to 164 µg/m^3), for a reduction of about 67-72%. However, as is also evident in Figure 4, the average annual ozone concentration has increased steadily over the period 1973 to 2006 at an average rate of 0.55 ppb/year, tripling from 9 ppb (18 µg/m^3) in 1973 to 27 ppb (54 µg/m^3) in 2006. Therefore, while the peak ozone concentrations have been successfully reduced over time, the average ozone concentrations have increased. As discussed in more detail below, the increase in annual average ozone concentrations appears to be associated with increasing global background levels. The progress in reducing maximum ozone concentrations indicates that the regional control program has more than offset the increase in global background.

This increase has not been restricted to the average annual concentration (50th percentile) alone, but is also evident at other percentile levels across all monitoring locations in the LFV. This is illustrated in Figures 5 through 14 for stations T2, T4, T9, T11-T33, T12, T15, T17, T18, T27, and T29. These trends in increasing ozone concentrations in the LFV have been previously noted by Vingarzan and Taylor (2003).[9] The authors noted that while the raw, unadjusted trends in observed ozone concentrations indicated an increase in ozone concentrations over the period 1985 to 2001, meteorologically adjusted trends in the LFV were spatially variable—stations in the western portion of the LFV exhibited positive trends (i.e., increasing ozone levels), while more easterly stations exhibited negative trends (i.e., decreasing ozone concentrations). Declines in average annual concentrations ranged from 0.19 to 0.29 ppb/year, or about 0.57% to 1% per year. Meteorologically adjusted long-term trends in summer ozone (May-September) showed decreasing concentrations at all stations in the LFV, with declines ranging from 0.14 to 0.94 ppb/year.

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[9] Vingarzan, R and B. Taylor 2003. Trend Analysis of Ground Level Ozone in the Greater Vancouver/Fraser Valley Area of British Columbia. Atmospheric Environment 37:2159-2171.

Figure 4
Trends in O_3 Concentrations at NAPS Stations in the LFV

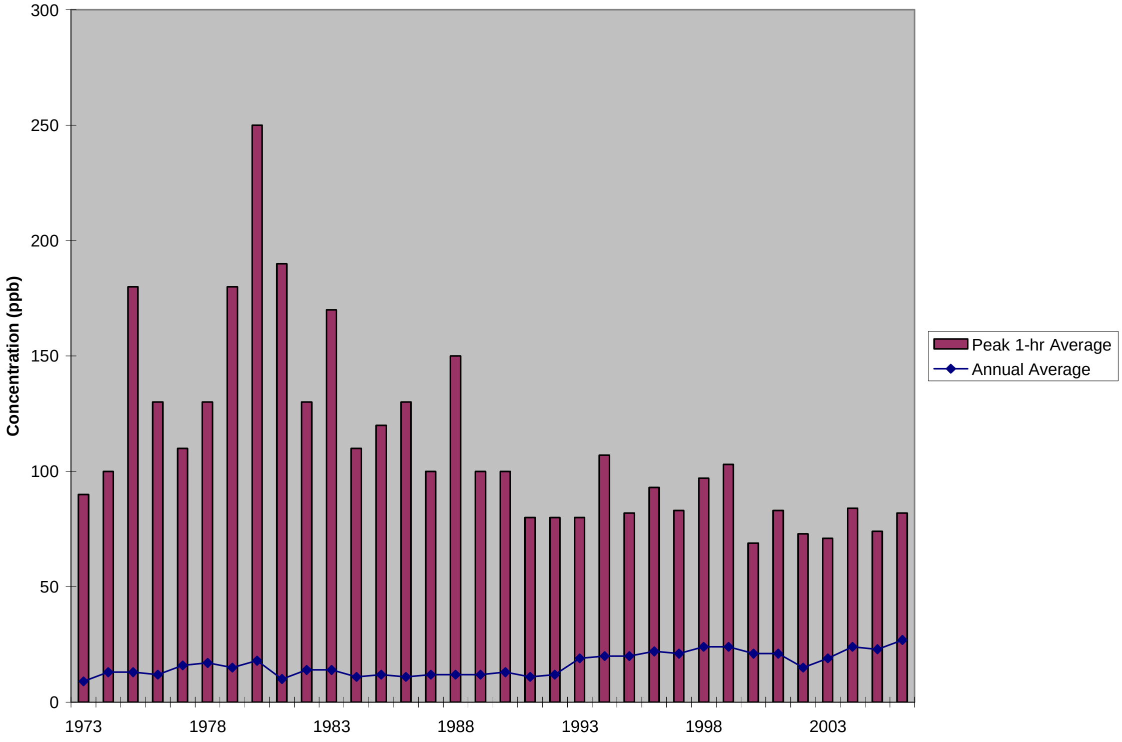


Figure 5
Trends in O_3 Concentrations at Kitsilano (T2)

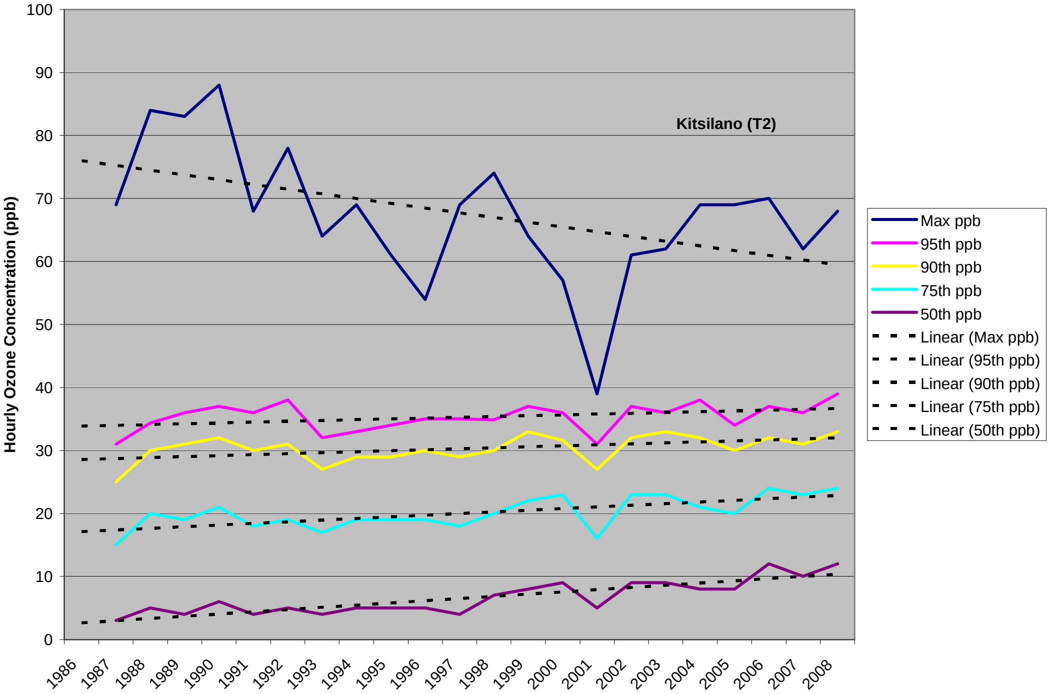


Figure 6
Trends in O_3 Concentrations at Kensington Park (T4)

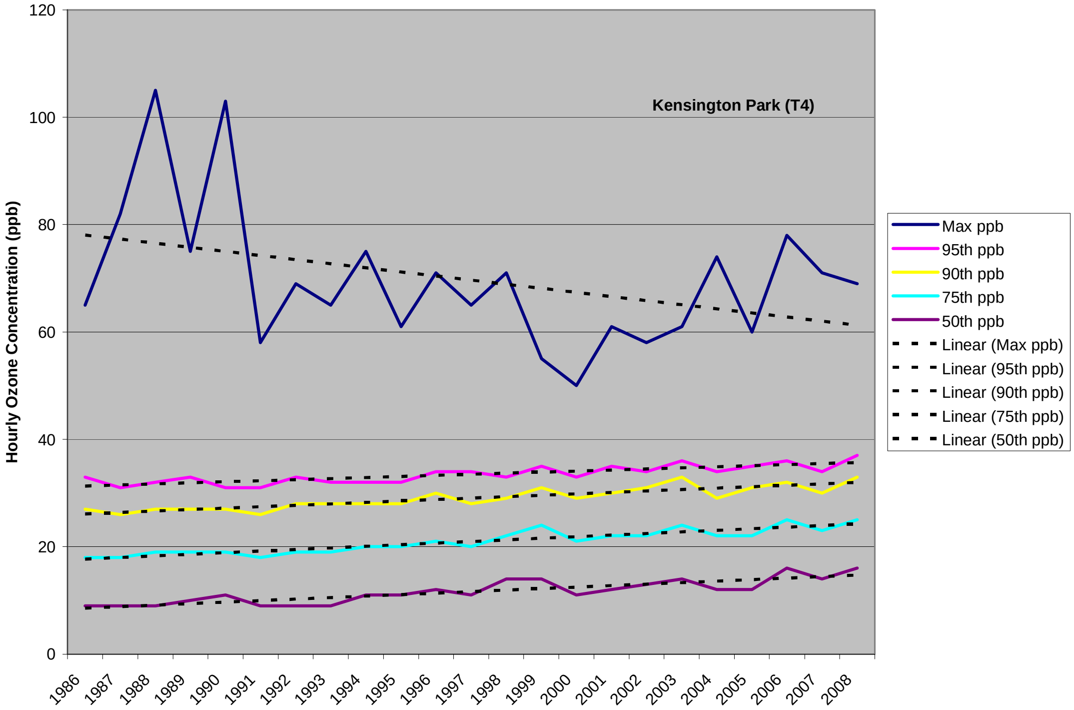


Figure 7
Trends in O_3 Concentrations at Port Moody (T9)

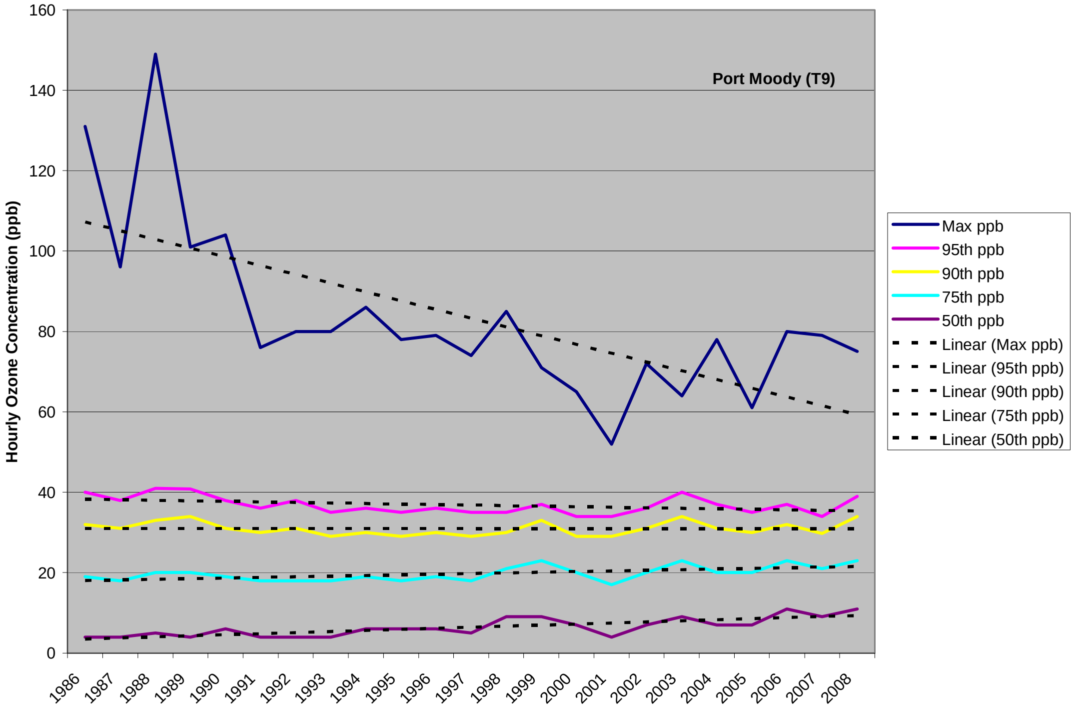


Figure 8
Trends in O_3 Concentrations at Richmond South (T17)

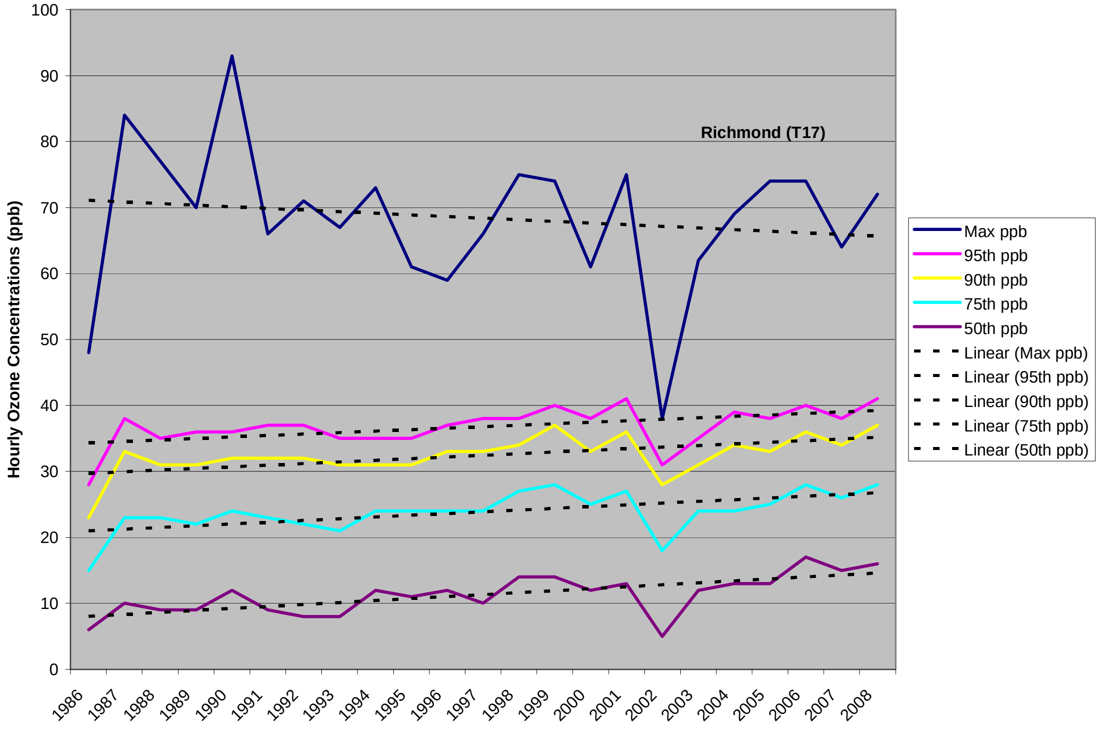


Figure 9
Trends in O_3 Concentrations at Burnaby South (T18)

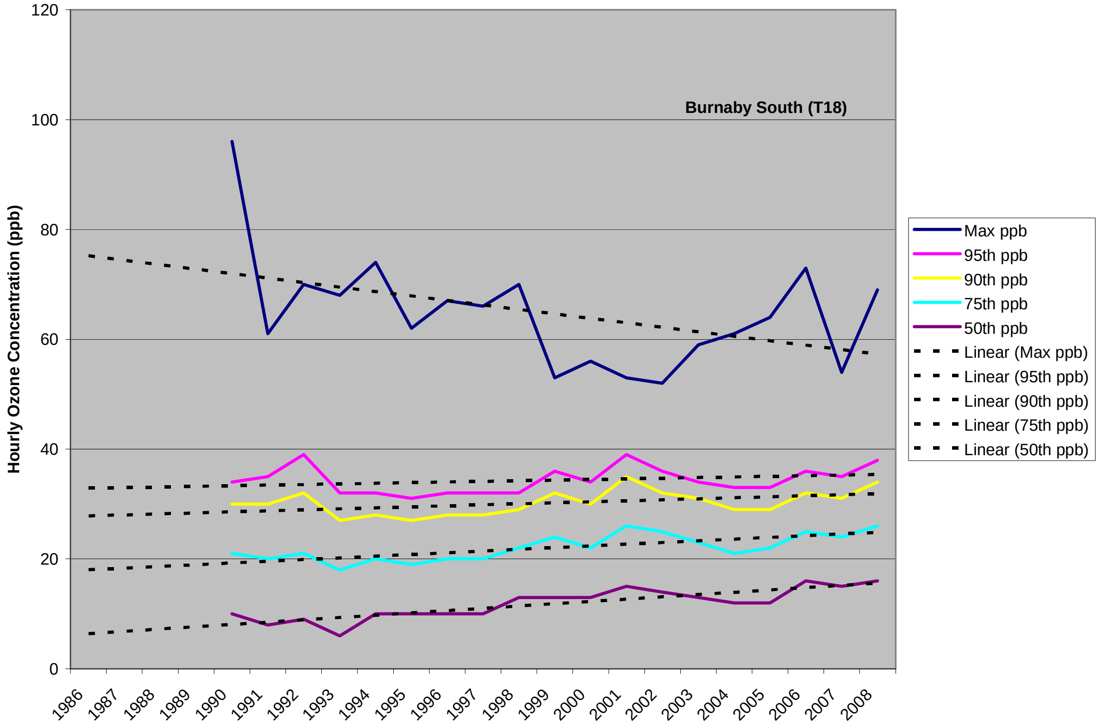


Figure 10
Trends in O_3 Concentrations at Surrey East (T15)

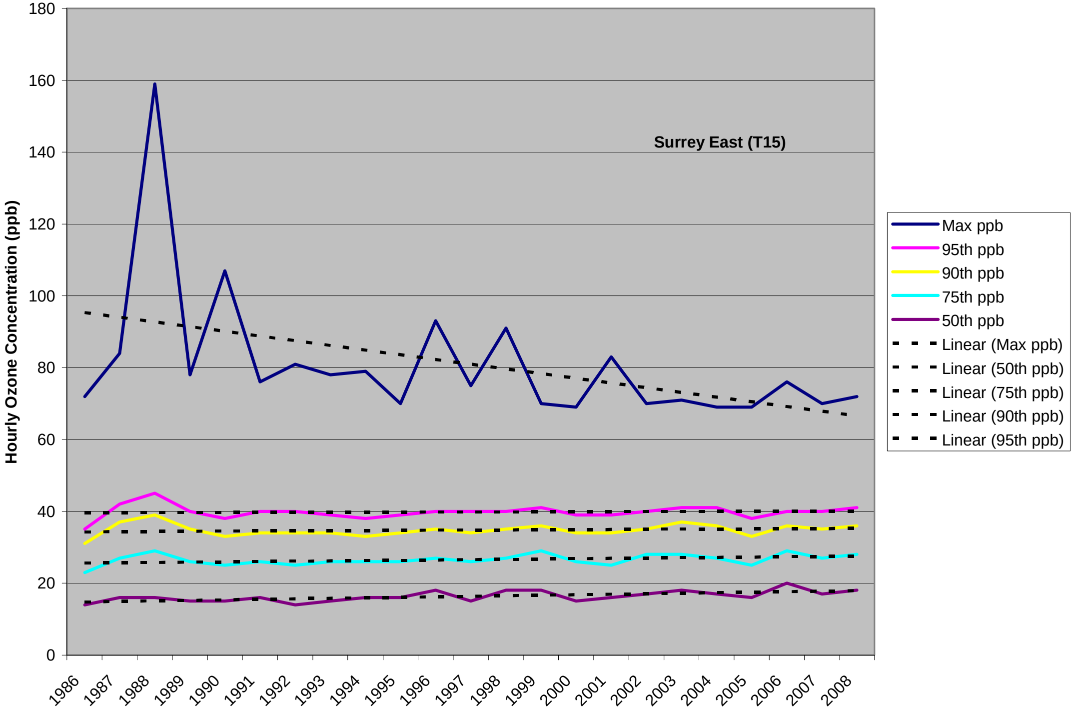


Figure 11
Trends in O_3 Concentrations at Langley (T27)

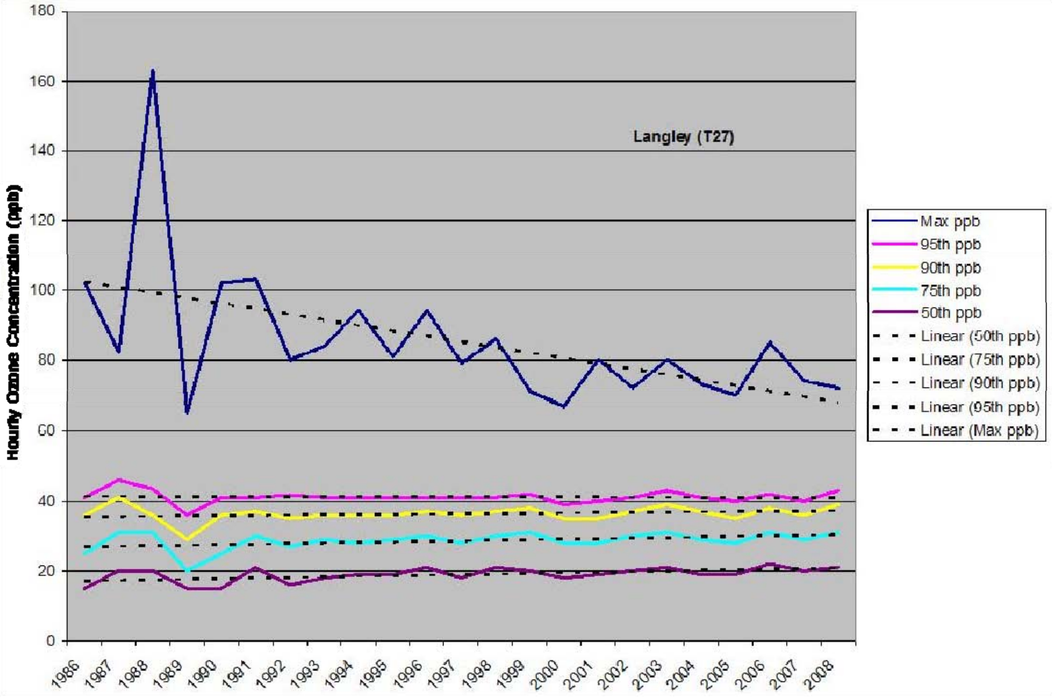


Figure 12
Trends in O_3 Concentrations at Abbotsford (T11-T33)

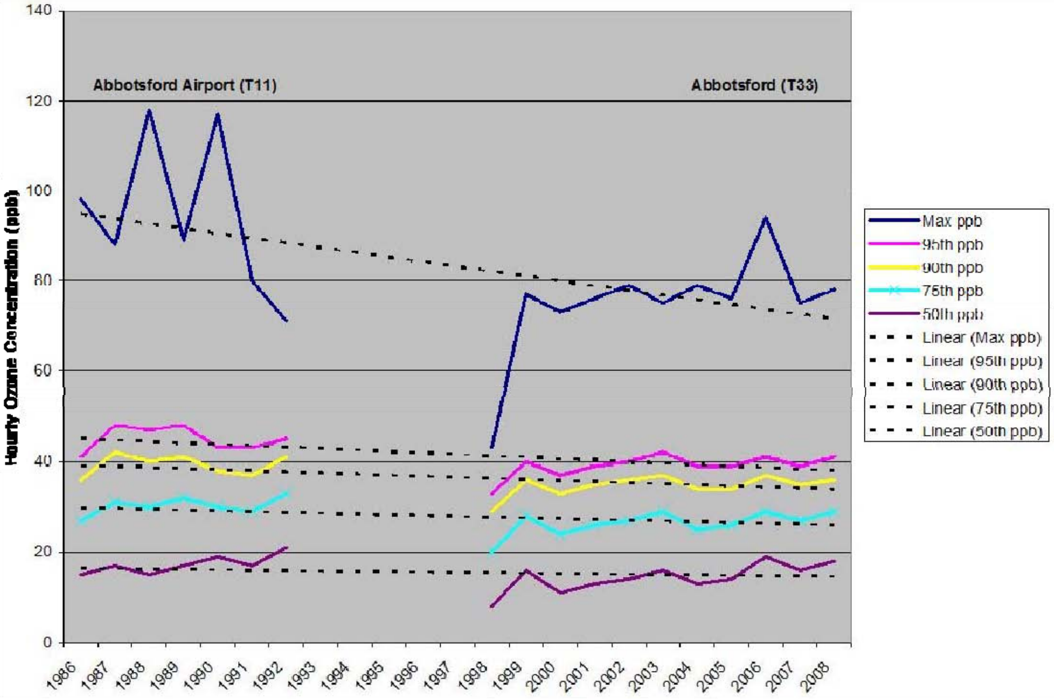


Figure 13
Trends in O_3 Concentrations at Chilliwack (T12)

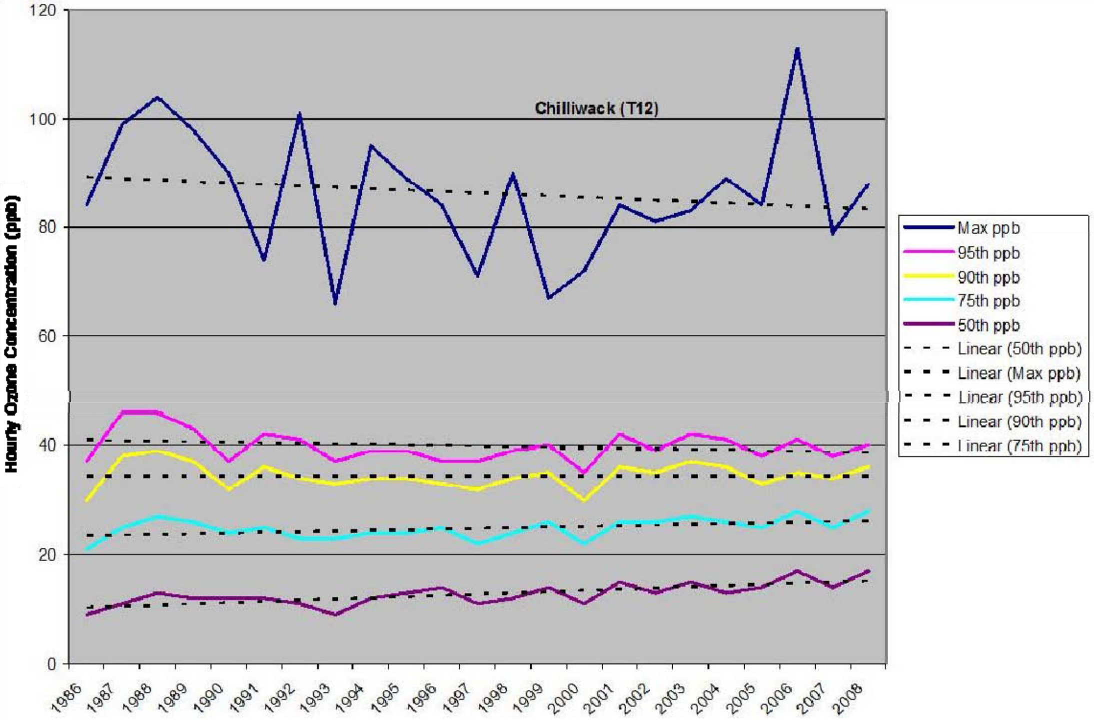
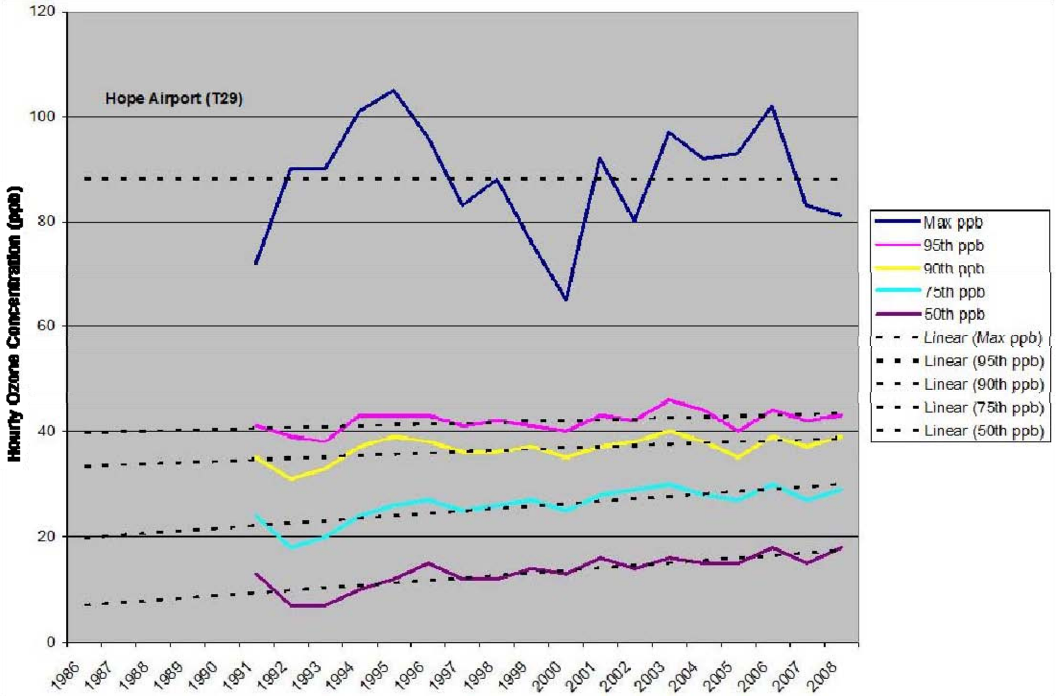


Figure 14
Trends in O_3 Concentrations at Hope (T12)



Increasing trends to higher ozone concentrations at lower percentile levels in the LFV were most recently raised by Drs. D.G. Steyn, C. Reuten, B. Ainslie of the University of British Columbia and P. Jackson of the University of Northern British Columbia in a June 11, 2009 progress report to the Steering Committee of the Fraser Valley Ozone Research Project. The trends toward increasing ozone levels were noted to be similar to levels in the United Kingdom and elsewhere in the Northern hemisphere as reported by Jenkin (2008),[10] and have been reported for other locations by Derwent et al. (2007),[11] Oltmans et al. (2006),[12] Simmonds et al. (2004),[13] and Brönnimann et al. (2002).[14] Vingarzan (2004) attributed the rise in global background ozone concentrations to the following:

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[10] Jenkin, M.E. 2008. Trends in Ozone Concentration Distributions in the UK Since 1990: Local, Regional and Global Influences. Atmospheric Environment 42:5434-5445.

[11] Derwent, R.G., P.G. Simmonds, A.J. Mannng and T.G. Spain. 2007. Trends Over a 20-year Period from 1987 to 2007 in Surface Ozone at the Atmospheric Research Station, Mace Head, Ireland. Atmospheric Environment 41:9091-9098.

[12] Oltmans, S.J., A.S. Lefohn, J.M. Harris, I. Gabally, H.E. Scheel, G. Bodeker, E. Brunke, H. Claude, D. Tarasick, B.J. Johnson, P. Simmonds, D. Shadwick, K.Anlauf, K. Hayden, F. Schmidlin, T. Fujimoto, K. Akagi, C. Meyer, S. Nichol, J. Davies, A. Redondas and E. Cuevas 2006. Long-term Changes in Tropospheric Ozone. Atmospheric Environment 20:3156-3173.

[13] Simmonds, P.G., R.G. Derwent, A.L. Manning and G. Spain. 2004. Significant Growth in Surface Ozone at Mace Head, Ireland, 1987-2003. Atmospheric Environment 38:4769-4778.

[14] Brönnimann, S., B. Buchmann and H. Wanner. 2002. Trends in Near-Surface Ozone Concentrations in Switzerland: the 1990s. Atmospheric Environment 36:2841-2852.

- Changes in emissions of ozone precursors (i.e., NOx) from fossil-fuel combustion since the 1970s;

- Increased methane emissions from the late 1970s to the late 1980s;

- Changes in stratospheric-tropospheric ozone exchange and the effect of declining stratospheric ozone on UV radiation reaching the lower troposphere; and

- Intercontinental transport of Asian air pollution, especially in the spring.

According to Vingarzan,[15] more recent (unpublished) analyses of ozone trends in the LFV indicate that the increase in ground-level ozone concentrations at the lower percentile levels (e.g., 10th to 25th percentiles) is likely due to the influence of increasing global background ozone concentrations. However, the analyses also indicate that, when adjusted for meteorological influences, the trends in ozone concentrations in the LFV at the upper percentile levels show a marked decline in concentrations in the LFV from the early 1980s to the early 1990s, but little-to-no change in concentrations from the early 1990s to the present (i.e., during the lifetime of the Aircare program). For example, Statistics Canada (2007, op. cit.) reported no statistically significant change in 8-hour averaged ozone concentrations for 11 monitoring locations in the LFV over the period 1990-2005. Vingarzan states that although there has been a significant decline in the atmospheric NOx/VOC ratio due to reductions in emissions implemented as a result of the 1994 and 2005 AQMPs, simultaneous reductions in both NOx and VOC emissions have not resulted in improvements in the LFV ozone levels. This indicates that the LFV airshed is HC-limited. As such, further reductions in NOx emissions would not be expected to produce improvements in ozone concentration levels. Rather, it would appear that the emphasis for future AQMP strategies should focus on VOC emission reductions.

3.2.3 Nitrogen Dioxide – NOx emissions primarily result from the reaction between nitrogen and oxygen that occurs during high temperature combustion processes. Nitric oxide (NO) is the primary NOx emission produced by combustion, but several percent of the NOx may be emitted in the more harmful form of nitrogen dioxide (NO_2). Atmospheric processes also convert some of the NO to NO_2. NOx emissions are important pollutants in the lower atmosphere for several reasons. First, NO_2 is directly harmful to humans, irritating the mucosa of the eyes, nose, throat, and respiratory tract. Second, NO_2 reacts with oxygen to form ozone in the presence of sunlight. Third, NOx emissions contribute to the formation of nitrate particles, a component of PM_{10} and $PM_{2.5}$. Finally, NO_2 imparts an orangey-red colour to the atmosphere.

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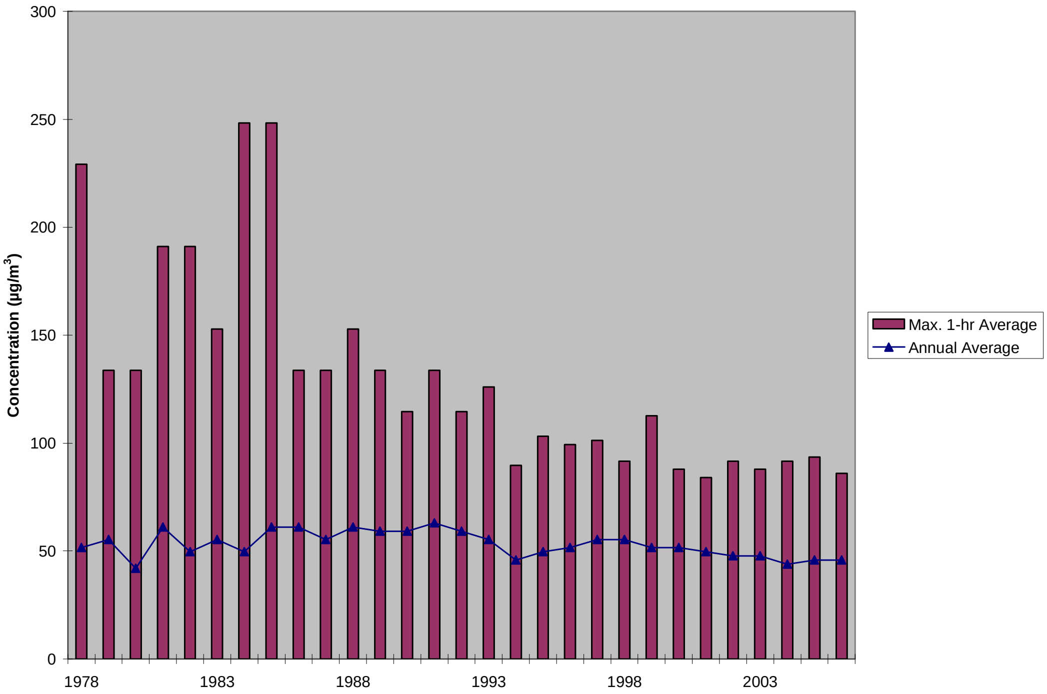
[15] Vingarzan, R. personal communication, January 26, 2010.

Metro Vancouver has adopted ambient air quality objectives of 200 µg/m^3 (1-hour average) and 40 µg/m^3 (annual average) for NO_2 concentrations. Figure 15 indicates that the levels of NO_2 at NAPS stations in the LFV were highest in the late 1970s and early 1980s, but that peak 1-hour average concentrations had declined significantly by the early 1990s. The ambient air quality objective for 1-hour average NO_2 concentrations is being achieved. While annual average NO_2 concentrations have declined from greater than 60 µg/m^3 in the early 1980s to 45.8 µg/m^3 by 2006, continued reductions in NOx emissions would be required to achieve the annual average objective of 40 µg/m^3.

Figure 15
Trends in NO_2 Concentrations at NAPS Stations in the LFV

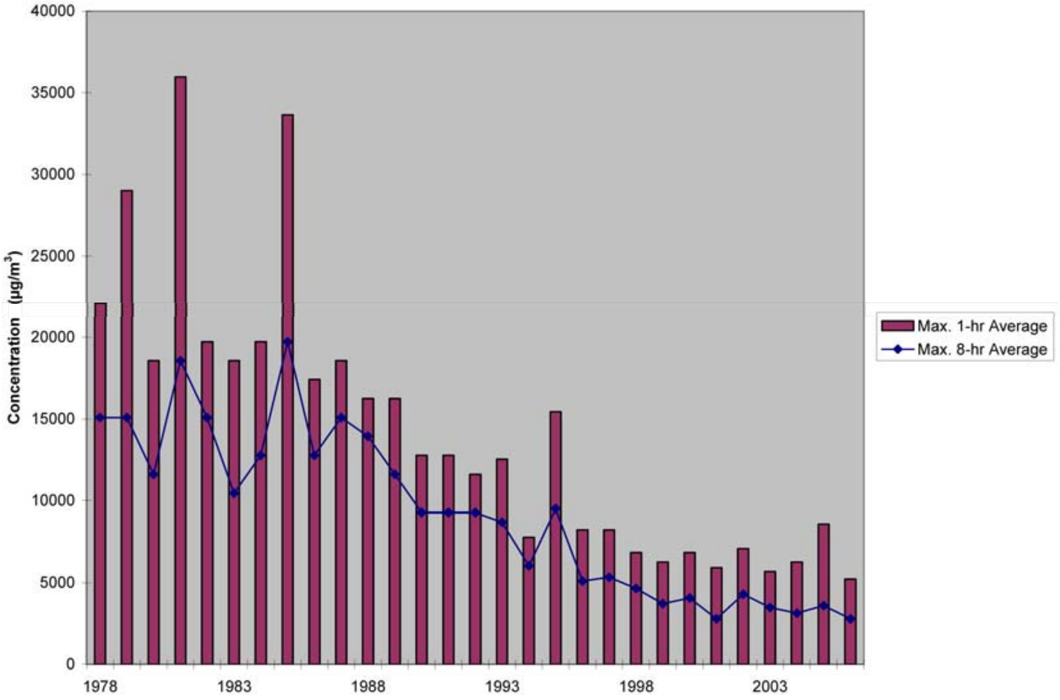


3.2.4 Carbon Monoxide – Carbon monoxide is produced by both natural and anthropogenic sources (e.g., automobile emissions, home heating). Natural sources include volcanic eruptions, forest fires, and the decomposition of organic materials. Human emissions of CO are primarily caused by the incomplete combustion of fossil fuels.

CO is an odourless, colourless, tasteless gas. When inhaled, CO can combine with haemoglobin to form carboxyhaemoglobin (COHb), which reduces the oxygen-carrying capacity of the blood and impairs the release of oxygen to extra-vascular tissues. This can lead to hypoxia, and cause toxic effects on brain, heart and muscular tissues, and can affect a developing fetus.

The ambient air quality objectives adopted by Metro Vancouver for CO are 30,000 µg/m^3 (1-hour average) and 10,000 µg/m^3 (8-hour average). Figure 16 shows that the 1-hour average objective was achieved at the NAPS monitoring sites in the LFV by 1986, and that the 8-hour average objective has been achieved since 1990. CO levels have continued to decline since the early 1990s.

Figure 16
Trends in CO Concentrations at NAPS Stations in the LFV



3.3 Emission Inventory Trends

Estimated emissions of common air contaminants in the Lower Fraser Valley (LFV) from 1990 to 2030 were derived by Metro Vancouver.[16] These include gaseous emissions (CO, NOx, Sulphur Oxides [SOx], VOC, and NH_3), as well as particulate matter (PM_{10} and $PM_{2.5}$) and greenhouse gases. The inventory includes emissions from all sources in Metro Vancouver, the Fraser Valley Regional District, and Whatcom County, WA.

The following sections provide a brief discussion of the major sources of emissions for each contaminant and the trends for past and anticipated future emissions. Note that the emissions from light- and heavy-duty vehicles from 2005 to 2030 are those that were originally estimated by Metro Vancouver for the most recent comprehensive emission inventory. Revised estimates for these two categories are provided later in Section 8, based on the modelling completed by Sierra Research for the AirCare review.

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[16] Metro Vancouver 2007. 2005 Emission Inventory and Forecast & Backcast. Burnaby, BC.

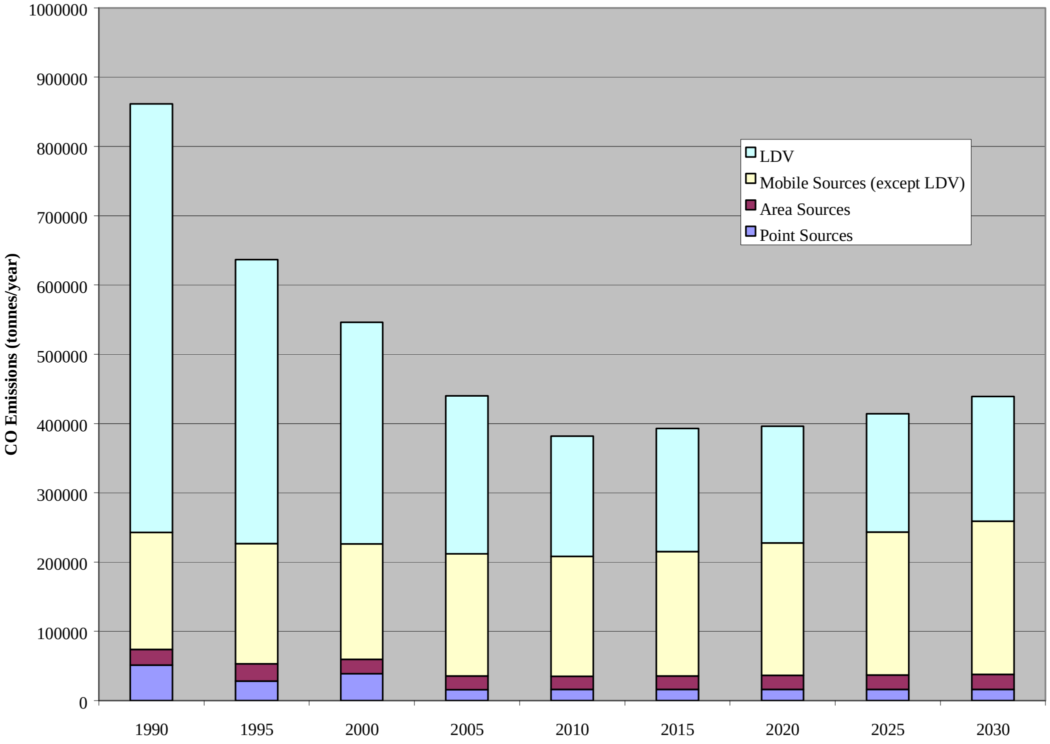
3.3.1 Carbon Monoxide (CO) - As indicated in Table 3, light-duty vehicle (LDV) emissions were the dominant source of CO emissions in the LFV over the period 1990-2005, accounting for up to 72% of total emissions in 1990. By 2005, CO emissions from LDV had been reduced by 63% from 1990 levels, and accounted for only 51.9% of total CO emissions. It was projected that CO emissions from LDV would continue to decline until 2020, and only increase slightly from 2020 to 2030 due to increased emissions from non-road equipment, space heating (i.e., buildings) and mobile sources such as aircraft and LDV. The slight increase in CO emissions from LDV after 2015 was assumed to reflect LDV emissions after the end of the current AirCare program contract. In the year 2030, it was anticipated that CO emissions from LDV would account for just 41% of total emissions in the LFV.

Table 3
Trends in CO Emissions in the LFV (tonnes per year)

	1990	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Point Sources									
Petroleum Products	1268	836	946	1415	1434	1450	1462	1475	1487
Electric Power Generation	193	485	381	28	56	62	25	16	11
Bulk Shipping Terminals	1	0	1	1	1	1	1	1	1
Chemical Manufacturing	76	34	46	45	41	49	56	63	70
Metal Foundries and Metal Fabrication	616	359	34	38	41	42	44	46	47
Waste-to-Energy	17	14	26	31	31	31	31	31	31
Non-metallic Mineral Processing Industries	514	600	2274	2798	2946	2807	2811	2815	2819
Paper and Allied Products	4939	488	1069	171	122	123	123	124	124
Primary Metal Industries	39754	22551	31684	10308	10308	10308	10308	10308	10308
Wood Products	1990	888	423	434	499	530	539	546	554
Other Point Sources	1605	1738	1813	516	571	590	709	736	755
Sub-total Point Sources	**50973**	**27996**	**38698**	**15783**	**16050**	**15993**	**16110**	**16160**	**16208**
Area Sources									
Burning	8181	9093	6658	10242	9016	9064	9113	9162	9211
Heating	14458	15552	13720	9182	9624	10168	10871	11567	12250
Miscellaneous Area Sources	130	157	131	99	110	119	127	134	141
Sub-total Area Sources	**22770**	**24803**	**20509**	**19523**	**18751**	**19351**	**20111**	**20864**	**21603**
Mobile Sources									
Light-Duty Vehicles	618725	410212	319992	228281	173683	177737	168445	171172	179983
Heavy-Duty Vehicles	26176	20948	10101	4937	2996	2479	2556	2722	2989
Aircraft	7195	6035	7349	6692	7596	8203	8824	10398	11570
Railways	805	843	729	529	546	557	563	577	586
Marine	809	910	1004	1012	1144	1296	1432	1575	1714
Other Non-road Equipment	134029	145843	147816	163116	160868	166984	177879	190693	204369
Sub-total Area Sources	**787739**	**584790**	**486991**	**404566**	**346833**	**357256**	**359699**	**377137**	**401212**
Total LFV	**861481**	**637588**	**546199**	**439872**	**381633**	**392600**	**395921**	**414160**	**439023**

Figure 17 depicts the trend in overall emissions from point and area sources, as well as emissions from LDV and other mobile sources as separate categories. Despite the projected increase in CO emissions after 2010, Figure 17 indicates that CO emissions in the LFV in 2030 would still be 49% lower than they were in 1990, and that the largest reductions would be for LDV emissions.

Figure 17
Trends in CO Emissions in the LFV



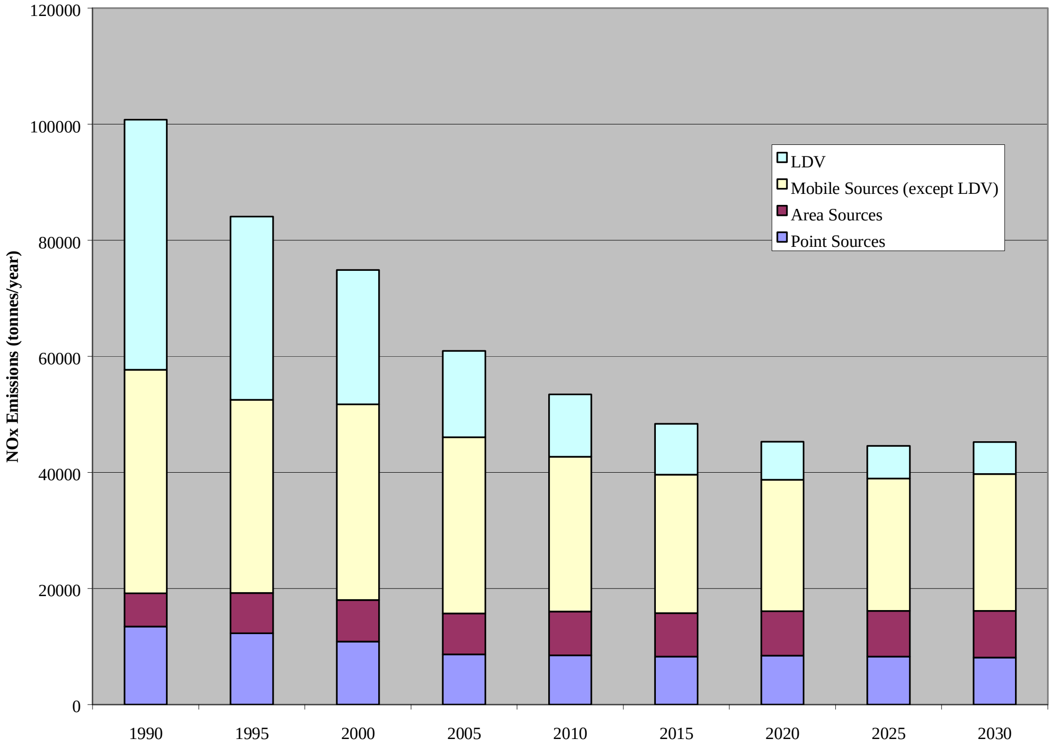
<u>3.3.2 Nitrogen Oxides (NOx)</u> – Table 4 lists the trends in NOx emissions in the LFV, and indicates that overall emissions have declined by 47% since 1990, from over 100,000 tonnes/year to less than 54,000 tonnes/year in 2010. NOx emissions are expected to continue to decline to about 45,000 tonnes/year by the year 2020 and remain at that level until 2030. Figure 18 shows the declining contribution of LDV emissions to total emissions in the LFV from 1990 to 2030. Overall LDV NOx emissions are projected experience an 87% reduction in emissions over the period 1990-2030.

Table 4

Trends in NOx Emissions in the LFV (tonnes per year)

	1990	1995	2000	2005	2010	2015	2020	2025	2030
Point Sources									
Petroleum Products	4,954	2,962	3,211	3,334	3,325	3,274	3,223	3,173	3,122
Electric Power Generation	514	1,762	1,816	174	205	260	209	131	90
Bulk Shipping Terminals	1	1	1	1	1	1	1	1	1
Chemical Manufacturing	229	115	140	141	126	95	79	62	46
Metal Foundries and Metal Fabrication	119	52	52	48	51	41	33	26	18
Waste-to-Energy	532	518	451	465	191	191	191	191	191
Non-metallic Mineral Processing Industries	5,075	5,225	3,827	3,636	3,739	3,644	3,648	3,651	3,654
Paper and Allied Products	399	331	319	130	88	70	53	36	19
Primary Metal Industries	56	50	56	95	95	95	95	95	95
Wood Products	768	320	223	207	222	200	177	153	130
Other Point Sources	786	969	718	433	416	394	718	729	713
Sub-total Point Sources	**13432**	**12303**	**10815**	**8664**	**8458**	**8266**	**8428**	**8248**	**8078**
Area Sources									
Burning	225	255	210	243	227	231	234	237	240
Natural Sources	846	846	846	838	838	838	838	838	838
Heating	4,657	5,829	6,153	5,931	6,488	6,376	6,584	6,793	6,981
Miscellaneous Area Sources	4	4	4	3	3	3	3	4	4
Sub-total Area Sources	**5732**	**6934**	**7213**	**7015**	**7556**	**7447**	**7659**	**7871**	**8062**
Mobile Sources									
Light-Duty Vehicles	43,125	31,577	23,139	14,889	10,745	8,794	6,554	5,594	5,511
Heavy-Duty Vehicles	16,455	9,196	8,357	6,508	4,252	2,443	1,444	910	561
Aircraft	1,093	1,077	1,168	1,122	1,276	1,418	1,573	1,751	1,941
Railways	5,027	5,261	4,562	3,727	3,269	3,103	2,924	2,802	2,678
Marine	6,508	7,357	8,419	8,375	9,091	10,243	11,311	12,468	13,582
Other Non-road Equipment	9,415	10,376	11,205	10,666	8,803	6,680	5,395	4,920	4,839
Sub-total Area Sources	**81624**	**64844**	**56848**	**45287**	**37435**	**32681**	**29201**	**28444**	**29112**
Total LFV	**100788**	**84081**	**74876**	**60966**	**53449**	**48394**	**45288**	**44563**	**45252**

Figure 18
Trends in NOx Emissions in the LFV



The primary source of NOx emission in 1990 was mobile sources, accounting for 81% of total emissions in the LFV. LDV alone accounted for almost 43% of total NOx emissions. Mobile sources remain the primary source of NOx emission in the LFV, responsible for about 70% of total emissions in 2010. However, the relative contribution of LDV to total NOx emissions has declined to just 20%, and was projected to continue to decline to about 12% of total emissions by 2030. At that time, NOx emissions from marine engines and space heating are expected to each exceed LDV emissions, and together are anticipated to account for 45% of total NOx emission in the LFV. However, NOx emissions from marine engines may be lower than has been presented in Table 4 due to lower emissions from newer vessels and normal fleet turnover of marine vessels by 2030. Figure 18 also indicates that NOx emissions are projected to be 55% lower in 2030 than they were in 1990, and that the largest reductions will have come from the reduction in LDV emissions.

3.3.3 Sulphur Oxides (SOx) – The estimated emissions listed in Table 5 indicate that industrial point sources (specifically petroleum refining, primary metals, and non-metallic mineral processing) were the primary sources of SOx emissions in the LFV prior to 2005, but that the relative significance of mobile sources to total emissions is expected to grow over the period 2010 to 2030. As such, the trend to lower SOx emissions from

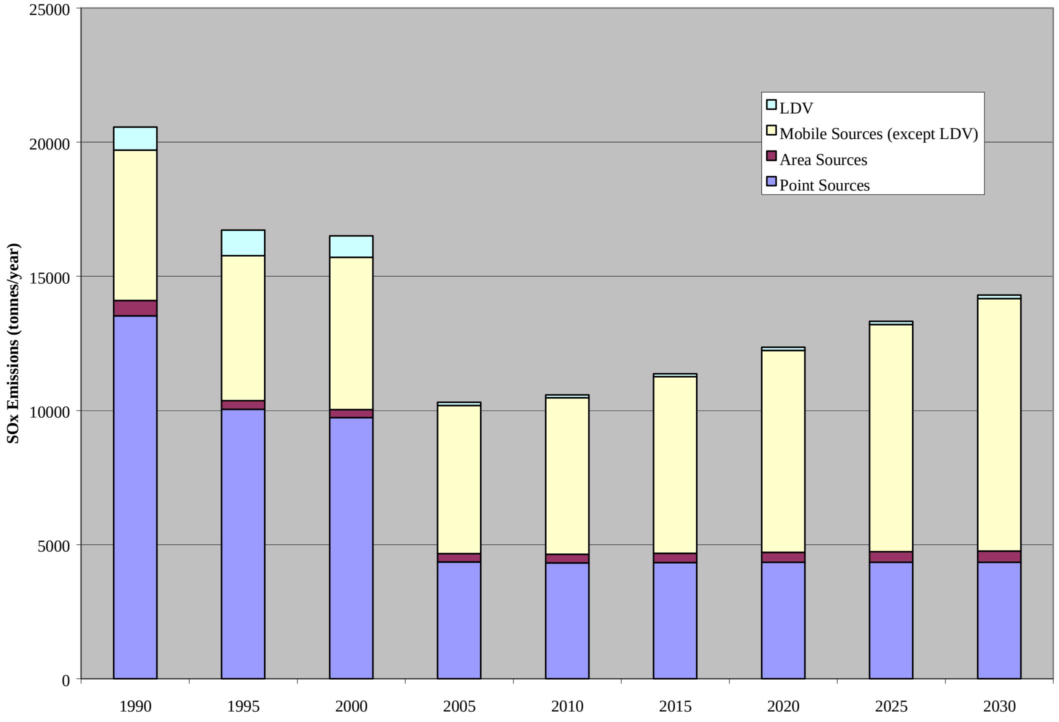
Table 5
Trends in SOx Emissions in the LFV (tonnes per year)

	1990	1995	2000	2005	2010	2015	2020	2025	2030
Point Sources									
Petroleum Products	6,875	5,407	4,807	2,345	2,348	2,351	2,352	2,354	2,356
Electric Power Generation	40	64	135	20	21	27	25	15	11
Chemical Manufacturing	20	4	9	3	4	4	5	5	6
Metal Foundries and Metal Fabrication	24	32	3	4	4	4	4	5	5
Waste-to-Energy	119	122	95	108	55	55	55	55	55
Non-metallic Mineral Processing Industries	1,247	657	223	209	210	209	209	209	209
Paper and Allied Products	59	98	59	5	5	5	5	5	5
Primary Metal Industries	5,013	3,594	4,383	1,609	1,609	1,609	1,609	1,609	1,609
Wood Products	76	23	16	12	14	15	15	15	15
Sub-total Point Sources	**13526**	**10042**	**9738**	**4361**	**4322**	**4333**	**4342**	**4339**	**4339**
Area Sources									
Burning	23	25	26	29	29	30	30	30	31
Heating	556	300	262	273	296	317	342	367	392
Sub-total Area Sources	**578**	**326**	**289**	**302**	**326**	**346**	**372**	**398**	**423**
Mobile Sources									
Light-Duty Vehicles	859	960	799	113	107	114	122	129	138
Heavy-Duty Vehicles	664	165	196	111	11	12	13	14	16
Aircraft	95	93	101	98	112	124	138	154	170
Railways	308	359	66	116	69	2	2	2	2
Marine	3,953	4,023	4,723	4,867	5,566	6,421	7,344	8,266	9,189
Other Non-road Equipment	581	758	299	335	71	22	24	25	27
Sub-total Mobile Sources	**6459**	**6358**	**6485**	**5639**	**5936**	**6696**	**7642**	**8591**	**9542**
Total LFV	**20563**	**16726**	**16512**	**10302**	**10584**	**11375**	**12356**	**13328**	**14304**

1990 to 2005 may be reversed in the future due to higher SOx emissions from marine vessels. This is illustrated in Figure 19, which shows the decline in total SOx emissions to 2005, with an increase in projected emissions to 2030. Total SOx emissions in the LFV in 2030 are expected to be 30% lower than they were in 1990. However, SOx emissions from marine engines may be lower than has been presented in Table 5 due to proposed reductions in the sulphur content of marine fuels in the future.

Figure 19 also shows that LDV contribute a relatively minor to insignificant amount of SOx emission to the total emission in the LFV. Furthermore, those emissions are not significantly affected by the Aircare program and would not change with or without the continuation of the program.

Figure 19
Trends in SOx Emissions in the LFV



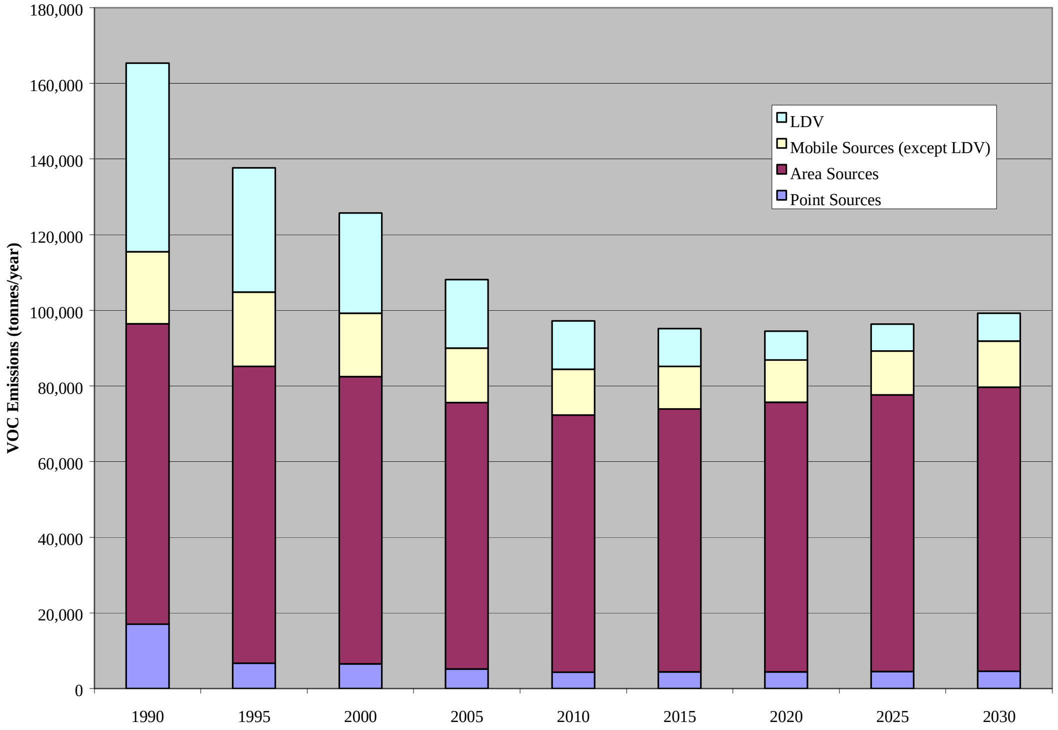
<u>3.3.4 Volatile Organic Compounds (VOC)</u> – Table 6 indicates that LDV emissions were the primary individual source of VOC emissions in the LFV in 1990, accounting for 30% of total emissions at that time. Other major sources included emissions from natural sources and solvent evaporation. However, VOC emissions from LDV have since declined such that emissions from natural sources and solvent evaporation currently represent larger sources of emissions than LDV. In fact, area sources, which include natural sources, are currently responsible for 70% of total VOC emissions in the LFV, while LDV account for only 13.2% of total emissions. Natural sources alone account for about 36% of total VOC emissions in the LFV in 2010.

Table 6
Trends in VOC Emissions in the LFV (tonnes per year)

	1990	1995	2000	2005	2010	2015	2020	2025	2030
Point Sources									
Petroleum Products	11,652	3,069	2,859	1,404	1,406	1,407	1,409	1,410	1,411
Electric Power Generation	31	126	92	8	18	20	6	4	3
Bulk Shipping Terminals	0	1	1	2	2	2	2	2	2
Chemical Manufacturing	444	218	134	154	127	120	123	125	128
Metal Foundries and Metal Fabrication	341	448	322	383	414	419	423	428	433
Waste-to-Energy	1	4	4	20	21	21	21	21	21
Non-metallic Mineral Processing Industries	117	108	64	145	153	146	146	146	147
Paper and Allied Products	280	89	119	28	14	14	15	15	15
Primary Metal Industries	151	92	21	33	33	33	33	33	33
Wood Products	650	645	769	932	702	734	742	748	755
Other Point Sources	3,352	1,961	2,219	2,063	1,466	1,514	1,566	1,613	1,656
Sub-total Point Sources	**17020**	**6760**	**6603**	**5172**	**4357**	**4429**	**4485**	**4545**	**4603**
Area Sources									
Agricultural	7,269	7,351	6,913	7,091	7,039	6,980	6,921	6,862	6,803
Burning	905	1,030	929	1,023	984	997	1,011	1,025	1,039
Gasoline Marketing	7,469	4,089	2,893	2,317	1,881	1,578	1,472	1,485	1,544
Landfills	266	263	294	109	103	108	112	115	119
Natural Sources	36,560	36,560	36,560	35,344	35,344	35,344	35,344	35,344	35,344
Solvent Evaporation	21,037	22,891	23,344	22,065	19,967	21,645	23,363	25,078	26,790
Heating	5,198	5,484	4,232	1,795	1,897	2,026	2,167	2,304	2,442
Miscellaneous Area Sources	683	757	736	692	753	805	858	907	955
Sub-total Area Sources	**79387**	**78424**	**75900**	**70436**	**67968**	**69484**	**71247**	**73119**	**75035**
Mobile Sources									
Light-Duty Vehicles	49,848	32,871	26,495	18,144	12,798	9,992	7,648	7,101	7,402
Heavy-Duty Vehicles	2,376	1,713	911	509	398	345	317	289	301
Aircraft	1,092	976	1,093	1,027	1,177	1,291	1,413	1,604	1,768
Railways	126	131	115	210	174	167	157	151	144
Marine	237	271	305	318	366	423	474	527	579
Other Non-road Equipment	15,261	16,536	14,278	12,337	9,968	9,021	8,779	8,996	9,400
Sub-total Mobile Sources	**68939**	**52497**	**43197**	**32544**	**24881**	**21238**	**18788**	**18669**	**19593**
Total LFV	**165346**	**137681**	**125700**	**108152**	**97206**	**95151**	**94520**	**96333**	**99231**

As illustrated in Figure 20, the relative proportion of LDV contributions is expected to continue to decline and account for less than 7.5% of total VOC emissions by 2030. Total VOC emissions in the LFV are projected to be 40% lower in 2030 than they were in 1990.

Figure 20
Trends in VOC Emissions in the LFV



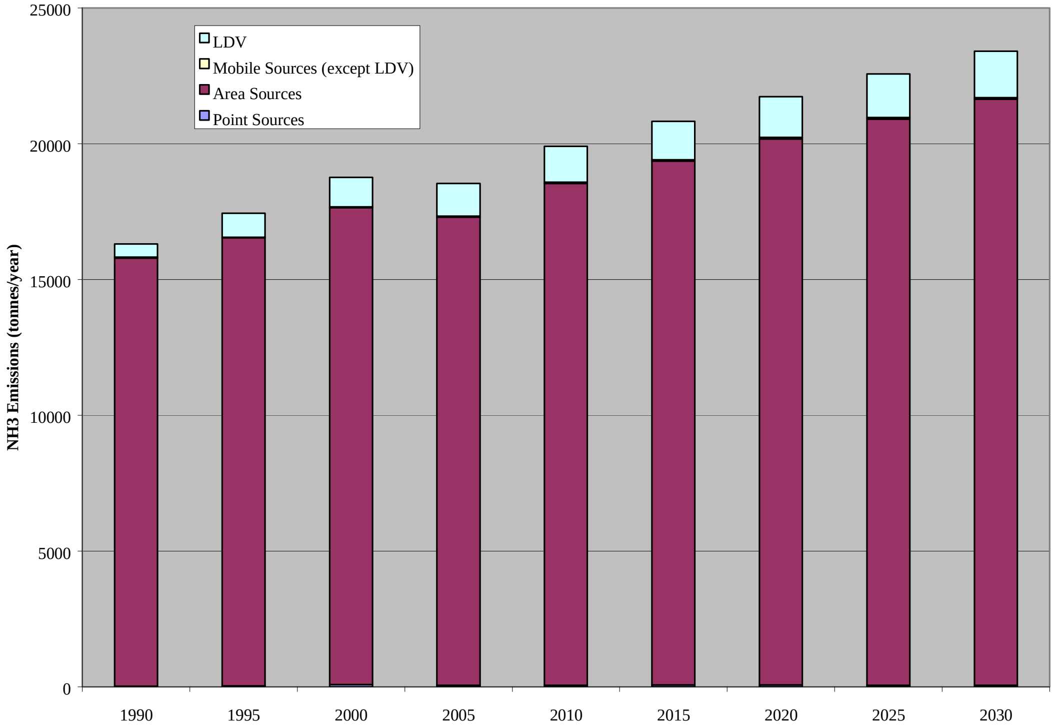
<u>3.3.5 Ammonia (NH_3)</u> – Table 7 lists the estimated NH_3 emissions in the LFV and indicates that these emissions are dominated by agricultural sources. Area sources typically account for over 90% of total emissions, and emissions from agricultural sources are projected to account for most (62.5%) of the projected increase in emissions from 1990 to 2030. By comparison, the contribution from LDV has increased from a low of 3% in 1990 to about 6.7% in 2010, and is projected to increase to 7.3% of total NH_3 emissions in the LFV by 2030.

This trend is illustrated in Figure 21. Overall, NH_3 emissions in the LFV are projected to be 43.5% higher in 2030 than they were in 1990.

Table 7
NH_3 Emission Trends in the LFV (tonnes per year)

	1990	1995	2000	2005	2010	2015	2020	2025	2030
Point Sources									
Petroleum Products	14	5	6	7	7	7	7	8	8
Electric Power Generation	-	24	35	24	24	32	30	19	13
Bulk Shipping Terminals	0	0	0	0	0	0	0	0	0
Chemical Manufacturing	-	-	2	3	3	3	4	4	4
Metal Foundries and Metal Fabrication	0	0	17	2	2	2	2	2	2
Non-Metallic Mineral Processing Industries	1	1	6	7	8	7	7	8	8
Paper and Allied Products	3	4	5	4	2	2	3	3	3
Wood Products	10	4	7	11	12	13	14	14	14
Other Point Sources	2	1	6	5	5	5	6	6	6
Sub-total Point Sources	**30**	**39**	**85**	**63**	**64**	**73**	**73**	**63**	**58**
Area Sources									
Agricultural	13,036	13,490	14,322	14,179	15,150	15,765	16,369	16,923	17,473
Burning	52	56	46	73	65	65	65	66	66
Landfills	309	307	310	122	122	128	129	130	132
Heating	428	429	487	476	495	504	527	549	571
Miscellaneous Area Sources	1,939	2,208	2,399	2,386	2,648	2,836	3,021	3,185	3,344
Sub-total Area Sources	**15764**	**16491**	**17564**	**17235**	**18479**	**19298**	**20111**	**20853**	**21587**
Mobile Sources									
Light-Duty Vehicles	488	874	1,082	1,207	1,323	1,414	1,506	1,603	1,706
Heavy-Duty Vehicles	17	19	21	22	24	26	28	30	33
Aircraft	0	0	0	0	1	1	1	1	1
Railways	0	0	0	1	1	1	1	1	1
Marine	4	5	5	6	7	8	8	10	11
Other Non-road Equipment	8	9	9	11	11	12	13	14	15
Sub-total Mobile Sources	**518**	**908**	**1118**	**1247**	**1365**	**1461**	**1557**	**1659**	**1768**
Total LFV	**16312**	**17438**	**18767**	**18545**	**19908**	**20832**	**21741**	**22575**	**23413**

Figure 21
Trends in NH_3 Emissions in the LFV



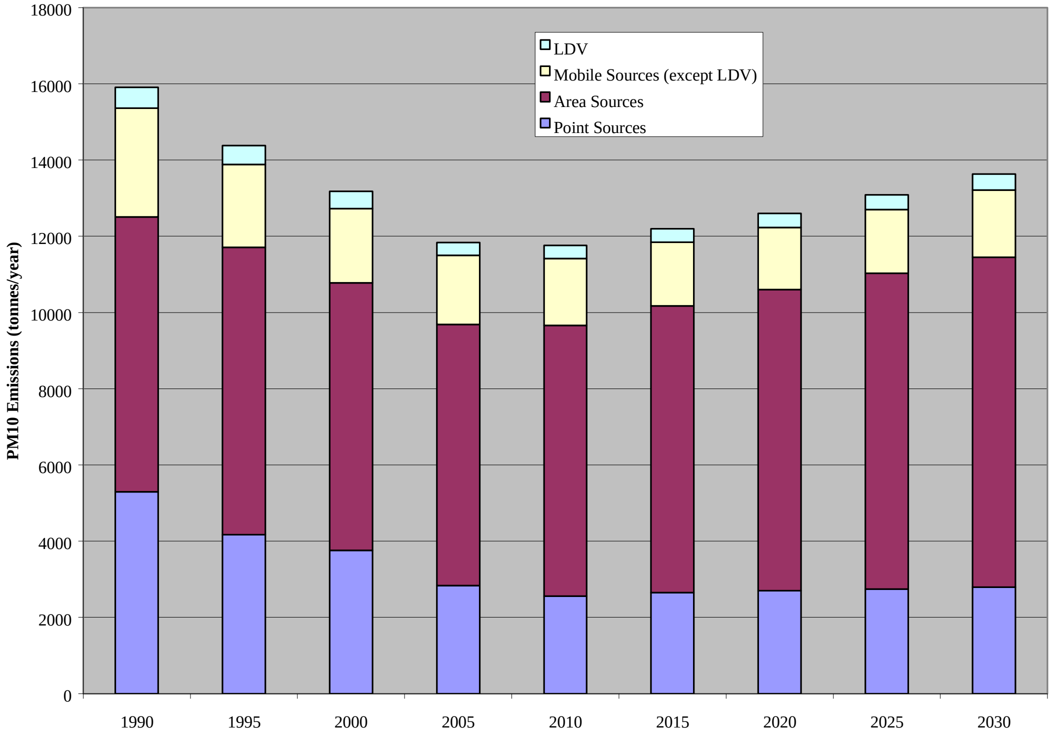
<u>3.3.6 Inhalable Particulate Matter (PM_{10})</u> – Table 8 indicates that overall PM_{10} emissions in the LFV decreased by over 25% between 1990 and 2005, but are projected to increase in the future to 2030. Between 1990 and 2005, the primary sources of reduced PM_{10} emissions included the wood products industry and on-road heavy-duty vehicles. Emissions from the latter are expected to continue to decrease in the future, while emissions from agricultural sources, space heating, other miscellaneous area sources, and marine engines are projected to increase in the future, although total emissions in 2030 will still be about 14% lower than in 1990.

LDV emissions contribute only a relatively small amount to the total PM_{10} emissions in the LFV, typically accounting for only about 3% of total emissions, as is illustrated in Figure 22.

Table 8
Trends in PM$_{10}$ Emissions in the LFV (tonnes per year)

	1990	1995	2000	2005	2010	2015	2020	2025	2030
Point Sources									
Petroleum Products	833	463	325	311	312	313	314	315	316
Electric Power Generation	43	192	159	36	46	57	42	26	18
Bulk Shipping Terminals	578	488	578	437	246	247	247	247	247
Chemical Manufacturing	19	10	7	16	17	20	23	25	28
Metal Foundries and Metal Fabrication	211	166	88	178	186	193	201	209	218
Waste-to-Energy	17	8	3	9	9	9	9	9	9
Non-metallic Mineral Processing Industries	524	583	434	455	478	477	489	500	511
Paper and Allied Products	399	292	278	240	224	228	231	235	238
Primary Metal Industries	386	259	644	118	118	118	118	118	118
Wood Products	1,868	1,320	946	731	617	665	680	690	702
Other Point Sources	420	391	292	305	306	328	351	372	394
Sub-total Point Sources	**5297**	**4172**	**3755**	**2836**	**2560**	**2655**	**2704**	**2747**	**2798**
Area Sources									
Agricultural	1,079	1,154	1,220	1,288	1,352	1,417	1,481	1,544	1,610
Burning	961	1,073	768	1,090	937	949	960	972	983
Landfills	68	55	37	59	74	57	57	57	56
Natural Sources	495	641	558	341	501	501	501	501	501
Heating	2,076	2,217	2,065	1,447	1,495	1,561	1,651	1,740	1,828
Miscellaneous Area Sources	2,530	2,401	2,375	2,627	2,744	3,038	3,250	3,464	3,677
Sub-total Area Sources	**7209**	**7540**	**7022**	**6852**	**7103**	**7522**	**7900**	**8279**	**8655**
Mobile Sources									
Light-Duty Vehicles	547	494	455	342	344	354	371	392	416
Heavy-Duty Vehicles	1,168	451	263	172	104	68	56	53	55
Aircraft	37	31	39	36	40	44	48	55	62
Railways	115	123	114	162	181	178	197	202	218
Marine	434	472	539	560	650	759	856	959	1,055
Other Non-road Equipment	1,098	1,096	992	878	776	614	466	400	374
Sub-total Mobile Sources	**3399**	**2666**	**2401**	**2150**	**2097**	**2017**	**1996**	**2062**	**2179**
Total LFV	**15905**	**14378**	**13178**	**11838**	**11760**	**12194**	**12600**	**13088**	**13632**

Figure 22
Trends in PM_{10} Emissions in the LFV



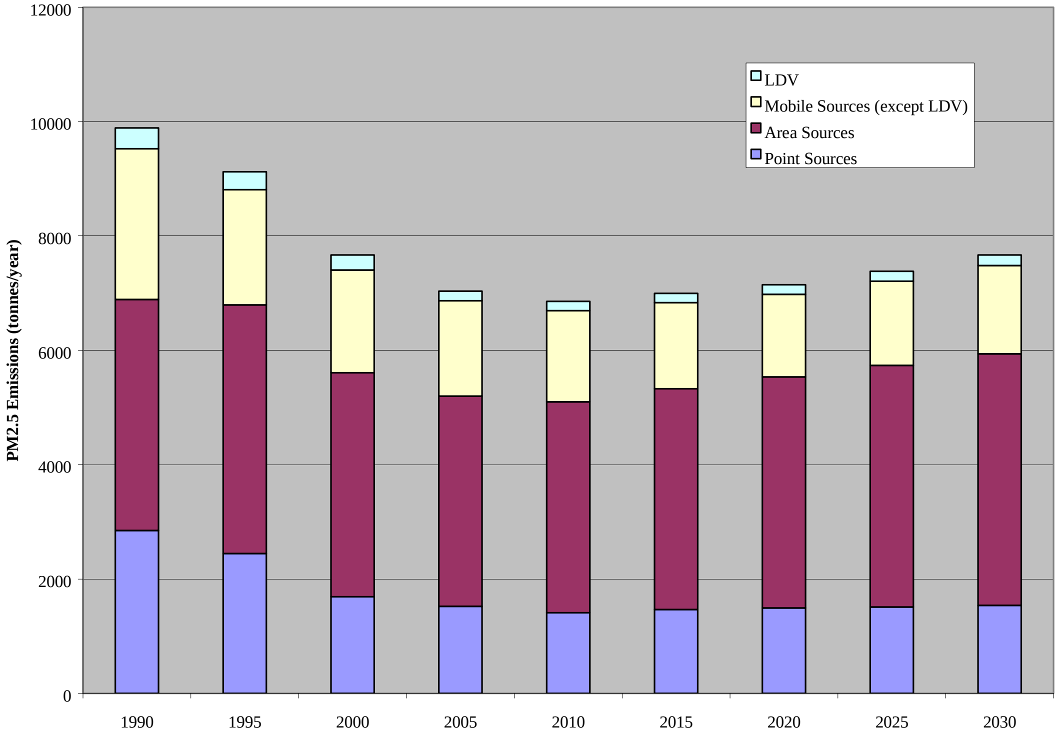
3.3.7 Fine Particulate Matter ($PM_{2.5}$) – The trend in $PM_{2.5}$ emissions summarized in Table 9 is similar to that described for PM_{10} emissions in the preceding section. Overall emissions declined by about 29% from 1990 to 2005, but are projected to increase between 2010 and 2030 from space heating, miscellaneous area sources, and marine engines. Nevertheless, total emissions in 2030 are still expected to be 22.5% lower in 2030 than they were in 1990.

$PM_{2.5}$ emissions from LDV never contributed more than 3.7% to total emissions in the LFV and have declined by 55% since 1990. Although emissions from LDV are projected to increase slightly by 2030, their contribution to total $PM_{2.5}$ emissions in 2030 will be only 2.4% of the emission inventory. The relatively small contribution of LDV emissions to total emissions in the LFV is illustrated in Figure 23.

Table 9
Trends in $PM_{2.5}$ Emissions in the LFV (tonnes per year)

	1990	1995	2000	2005	2010	2015	2020	2025	2030
Point Sources									
Petroleum Products	587	349	218	268	268	269	269	270	270
Electric Power Generation	43	192	159	36	46	57	42	26	18
Bulk Shipping Terminals	152	120	152	112	43	44	44	44	44
Chemical Manufacturing	13	6	6	13	14	17	19	21	24
Metal Foundries and Metal Fabrication	169	132	72	144	149	155	161	168	174
Waste-to-Energy	14	6	3	7	8	8	8	8	8
Non-metallic Mineral Processing Industries	226	234	141	145	151	152	156	160	164
Paper and Allied Products	309	240	225	191	179	181	184	187	190
Primary Metal Industries	96	231	91	55	55	55	55	55	55
Wood Products	955	661	424	326	270	290	296	300	305
Other Point Sources	285	274	195	222	225	240	257	272	287
Sub-total Point Sources	**2849**	**2445**	**1686**	**1519**	**1408**	**1467**	**1491**	**1511**	**1538**
Area Sources									
Agricultural	228	244	257	272	285	299	312	326	340
Burning	914	1,021	737	1,050	909	919	930	940	951
Landfills	18	14	10	16	19	15	15	15	15
Natural Sources	85	110	96	59	86	86	86	86	86
Heating	1,985	2,125	1,995	1,441	1,488	1,554	1,644	1,733	1,820
Miscellaneous Area Sources	807	835	822	843	904	989	1,057	1,123	1,187
Sub-total Area Sources	**4037**	**4349**	**3917**	**3680**	**3691**	**3862**	**4044**	**4223**	**4400**
Mobile Sources									
Light-Duty Vehicles	366	318	266	167	162	162	168	176	186
Heavy-Duty Vehicles	1,056	398	227	144	81	47	35	31	30
Aircraft	37	31	38	35	40	44	48	55	61
Railways	91	97	87	137	134	129	133	132	136
Marine	400	436	496	516	598	697	786	879	966
Other Non-road Equipment	1,055	1,051	950	836	741	584	441	376	350
Sub-total Mobile Sources	**3004**	**2330**	**2065**	**1835**	**1756**	**1663**	**1610**	**1649**	**1729**
Total LFV	**9890**	**9124**	**7668**	**7034**	**6855**	**6992**	**7145**	**7383**	**7667**

Figure 23
Trends in $PM_{2.5}$ Emissions in the LFV



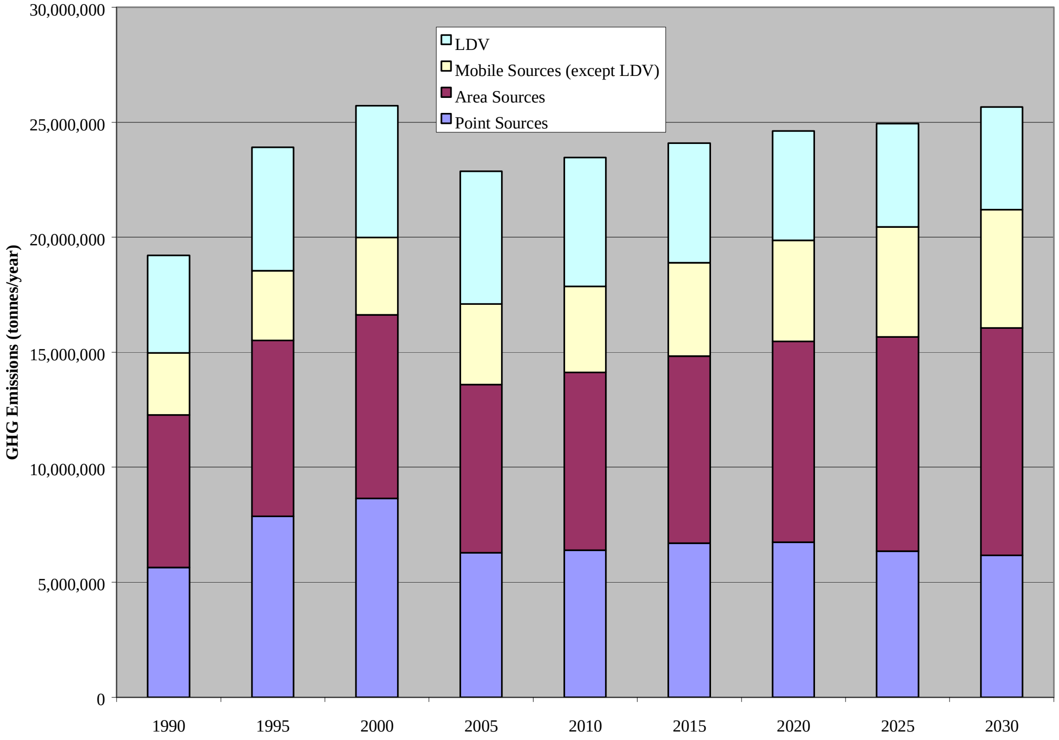
<u>3.3.8 Greenhouse Gases (GHG)</u> – GHG emissions comprise the sum of CO_2, CH_4 and N_2O emissions, expressed as CO_2 equivalent (CO_2eq). Table 10 shows that mobile sources are currently the largest source group for GHG emissions in the LFV, accounting for almost 42% of total GHG emissions in 2010. LDV emissions alone account for 23.9% of total LFV emissions, although those emissions are projected to decrease by about 20% by 2030 from 2010 levels. By comparison, GHG emissions from area sources are projected to increase by almost 30% from 2010 to 2030, with the largest increases coming from space heating.

As depicted in Figure 24, the overall trend in GHG emissions shows an increase in emissions from 1990 to 2000, a decline in emissions between 2000 and 2005 due to reductions in emissions from landfills, followed by a gradual increase in emissions from 2010 to 2030 such that total emissions in 2030 would be similar to emissions in 2000, but 33.6% higher than they were in 1990.

Table 10
Trends in GHG Emissions in the LFV (tonnes per year)

	1990	1995	2000	2005	2010	2015	2020	2025	2030
Point Sources									
Petroleum Products	2642863	1700244	1976122	2195071	2198198	2202362	2205570	2208843	2212183
Electric Power Generation	696547	3668719	3825496	987163	1068800	1390759	1216917	762386	521421
Bulk Shipping Terminals	881	640	919	1032	1141	1141	1141	1141	1141
Chemical Manufacturing	137074	56862	68942	64397	58537	70374	80838	90667	100584
Metal Foundries and Metal Fabrication	109189	43125	50597	55995	59474	61658	64050	66594	69189
Waste-to-Energy	101506	104949	107774	116746	119871	119871	119871	119871	119871
Non-metallic Mineral Processing Industries	1267572	1552006	1901584	2040901	2123323	2059570	2067866	2075050	2082873
Paper and Allied Products	210159	184791	209493	127455	74454	75213	75921	76634	77346
Primary Metal Industries	20168	17891	19995	166428	166428	166428	166428	166428	166428
Wood Products	128388	132555	120415	137642	125994	137203	140487	142941	145717
Other Point Sources	324636	402172	362134	392872	390760	410208	607363	642493	664181
Sub-total Point Sources	**5638982**	**7863952**	**8643472**	**6285701**	**6386979**	**6694787**	**6746452**	**6353047**	**6160933**
Area Sources									
Agricultural	1105747	1125795	1084067	1105999	1117803	1126106	1134851	1144111	1154339
Burning	77786	86138	78550	75774	69338	70528	71716	72903	74091
Gasoline Marketing	37	30	30	43	48	50	52	54	57
Landfills	888643	882967	891638	402765	350352	367966	370282	373874	380282
Heating	4500372	5478283	5848203	5655973	6131101	6501077	7075943	7652254	8202991
Miscellaneous Area Sources	58422	81738	84611	63454	66584	68913	73324	77958	82619
Sub-total Area Sources	**6631007**	**7654951**	**7987099**	**7304010**	**7735226**	**8134640**	**8726168**	**9321155**	**9894378**
Mobile Sources									
Light-Duty Vehicles	4235836	5360575	5737447	5781352	5608506	5204264	4753015	4498373	4458260
Heavy-Duty Vehicles	955255	1104091	1309649	1369126	1397884	1498210	1614168	1746475	1892413
Aircraft	245273	234640	255945	244964	281310	309683	339743	379592	417766
Railways	262580	274815	238277	217321	222497	227087	229420	234958	239004
Marine	373332	410776	437975	442262	496088	555448	609071	666137	721048
Other Non-road Equipment	869192	1005912	1116112	1230164	1341432	1469424	1606941	1746921	1885282
Sub-total Area Sources	**6941468**	**8390809**	**9095405**	**9285188**	**9347717**	**9264116**	**9152357**	**9272456**	**9613772**
Total LFV	**19211457**	**23909713**	**25725976**	**22874899**	**23469923**	**24093544**	**24624977**	**24946657**	**25669082**

Figure 24
Trends in GHG Emissions in the LFV



4. Trends in Emission Control Technology

Since the 1950s, it has been recognized that emissions from automobiles contribute to air pollution. Emissions of HC and NOx were identified as precursors to the formation of ozone, the principal ingredient of what is commonly referred to as "smog." Emissions of CO were known to contribute to unhealthful levels of CO in areas with traffic congestion.

The combustion of fuel containing lead additives was causing unhealthful levels of lead particles in urban areas. The conversion of sulfur in the fuel into sulfur dioxide (SO_2) during the combustion process is yet another issue. Small amounts of carbonaceous particles are directly emitted in the exhaust and gaseous emissions of HC, NOx, and SO_2 are transformed into "secondary" particles in the atmosphere. Brake pad wear is another source of particle emissions.

As emissions measurement techniques were refined, it became apparent that some of the HC emissions (e.g., benzene; 1,3-butadiene; acetaldehyde; and formaldehyde) were increasing public exposure to toxic air contaminants. In recent years, there has been concern about emissions of CO_2, leaking air conditioning refrigerant (HFC-134a), trace amounts of N_2O, and CH_4 because they are greenhouse gases.

Table 11 summarizes the various emissions and the associated environmental concern.

Table 11
Automobile Emissions

Emission	Environmental Concern
Hydrocarbons (HC) (also called "Volatile Organic Compounds" or "VOC")	Public health risk – precursors to ozone and particle formation, some are toxic air contaminants
Oxides of Nitrogen (NOx)	Public health risk – precursor to ozone, nitrogen dioxide, and particle formation, as well as acid rain
Carbon Monoxide (CO)	Public health risk – toxic at high concentrations
Lead (Pb)	Public health risk
Particulate Matter (PM)	Public health risk and impairment to visibility
Sulfur Dioxide (SO_2)	Public health risk – precursor to particle formation as well as acid rain
Carbon Dioxide (CO_2)	Greenhouse gas
HFC-134a (from A/C system leaks)	Greenhouse gas
Methane (CH_4)	Greenhouse gas
Nitrous Oxide (N_2O)	Greenhouse gas

The motor vehicle emissions control program in the U.S. and Canada has been primarily focused on reducing emissions of HC, CO, NOx, and lead particles. Lead particles have been eliminated through the removal of lead additives in gasoline. The sulfur content of gasoline is also controlled to the point that SO_2 emissions from light-duty vehicles are not an environmental concern. Greenhouse gas emissions are primarily related to fuel consumption, which has been controlled through Corporate Average Fuel Consumption (CAFC) standards in Canada and Corporate Average Fuel Economy (CAFE) standards in the U.S.

The remainder of this section is primarily focused on the control of HC, CO, and NOx emissions and how I/M programs have been used to maximize the control of these emissions. Since vehicle emissions controls were first imposed by the State of California, there have always been differences in the level of emissions control required in California, the other 49 states in the U.S., and in Canada. Vehicles meeting the more stringent California standards are often been voluntarily sold in other states and Canada. Since 1998, Canadian requirements have been harmonized with the U.S. The evolution of the standards described below focuses on when control technology was first required irrespective of whether it was uniformly required throughout the U.S. and Canada. Appendix A provides detailed information regarding the specific emission standards that applied to vehicles sold in Canada.

4.1 Uncontrolled Emissions

There are three source of HC from light-duty vehicles: crankcase vent emissions, evaporative emissions, and exhaust emissions. In the early 1960s, before there were any emissions controls on cars, EPA's MOBILE 6.2 model estimates that total uncontrolled HC emissions from gasoline-fueled light-duty vehicles were about 17 g/mi, about half coming from the exhaust and the other half from the combination of evaporative emissions and crankcase vent emissions. (To put that in perspective, passenger cars built in the early 1960s used about one gallon of fuel every 14 miles.[17] With that level of fuel consumption, they were consuming about 200 g/mi of fuel. An estimate of 17 g/mi of HC emissions means that about 8.5 percent of the fuel the vehicle was using was escaping in an unburned form.) Before emissions controls, CO emissions from gasoline-fueled light-duty vehicles were approximately 80 g/mi. NOx emissions were about 4.5 g/mi. PM emissions, primarily resulting from the use of leaded fuel, were approximately 0.25 g/mi. SO_2 emissions were negligible because of the low sulfur content of gasoline.

Few Diesel-powered light-duty vehicles were offered for sale prior to the imposition of emissions controls; however, tests of early 1970s vintage Mercedes Diesels indicate that they had about 95% lower HC and CO emissions than gasoline-fueled vehicles. NOx emissions were slightly lower. PM emissions were in the same range, but composed of carbonaceous particles rather than lead. Evaporative and crankcase emissions from Diesels were near zero.

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[17] T.C. Austin and K.H. Hellman, "Fuel Economy of the 1975 Models," U.S. Environmental Protection Agency, Society of Automotive Engineers Paper No. 740970, October 1974.

4.2 Pre-Catalyst Control Technology

As a result of regulations developed by the State of California, design changes to new vehicles were made to reduce emissions of unburned hydrocarbons (HC) and carbon monoxide (CO) beginning in the 1960s. Positive crankcase ventilation (PCV) systems were added to eliminate emissions from the crankcase vent beginning in 1963. Leaner carburetor calibrations and ignition retard were used to reduce HC and CO exhaust emissions beginning in 1966. Some vehicles were equipped with air pumps that injected air into the exhaust manifold to facilitate post-cylinder oxidation of HC and CO. (No controls were required on Diesel-powered vehicles because of their inherently lower emissions.)

The first evaporative emissions control systems were required in California beginning with the 1970 model year. Gasoline tank caps were no longer vented; instead, the gasoline tank was vented to a canister filled with activated carbon to trap HC vapors and subsequently burn them in the engine when the canister is purged.

The control of NOx emissions was first required in 1971 in California and in 1973 in other states and in Canada. (Appendix A provides a summary of standards applicable in Canada since 1971.) Exhaust gas recirculation (EGR) systems were the primary technique employed to meet the standards.

On the basis of the current test procedure, pre-catalyst-era emissions standards required 1974 model year vehicles to meet exhaust emission standards of 2.8 g/mi HC, 28 g/mi CO, and 3.1 g/mi NOx. Compared to uncontrolled emissions, HC and CO were reduced by about two-thirds and NOx by one-third. Maintenance of these reductions in customer service was frustrated by widespread “tampering” with emissions control devices. Disconnection of EGR systems was a popular technique to improve the degradation in driveability associated with the use of the first-generation systems. Removing air injection systems and richening the fuel:air mixture were also common modifications. The first I/M programs were focused on preventing this type of tampering and insuring that vehicles prone to spark plug fouling due to the use of leaded gasoline were free from misfire.

4.3 Early Catalyst Control Technology

A major step forward in exhaust emissions control took place in the 1975 model year, the first year that the California standards were stringent enough to require the use of catalytic converters on almost all new cars. The 1975 California exhaust emissions standards that forced the use of catalytic converters on most light-duty vehicles were 0.9 g/mi HC, 9.0 g/mi CO, and 2.0 g/mi NOx. Since then, emissions control requirements have become progressively more stringent throughout the U.S. and Canada.

From 1975 through 1979, most new light-duty vehicles were equipped with oxidation catalysts capable of reducing HC and CO emissions. Starting in 1980, the California NOx standard was lowered to the point that 3-way catalysts capable of simultaneously reducing HC, CO, and NOx emissions were required. The use of exhaust gas oxygen sensors (O_2 sensors) providing input to a feedback control system for fuel metering is necessary to achieve optimum performance from 3-way catalysts. Beginning in 1981, the U.S. NOx standard also required the widespread use of 3-way catalysts to meet the so-called "Tier 0" standards of 0.41 g/mi HC, 3.4 g/mi CO, and 1.0 g/mi NOx. These remained the U.S. standards for passenger cars through the 1993 model year.

Although many vehicles certified to meet U.S. standards were sold in Canada, vehicles not also sold in the U.S. were subject to Canadian standards that did not require the use of catalysts (2.0 g/mi HC, 25 g/mi CO, and 3.1 g/mi NOx) from 1975 through 1987.

During the first half of the 1975-1993 era, Diesel-powered light duty vehicles were able to meet the applicable standards with relatively minor improvements in injector design to reduce HC emissions. Diesels were also able to avoid the need for catalytic control of NOx emissions by certifying to optional 100,000-mile standards that allowed for higher NOx levels in exchange for greater durability. However, PM emission standards were tightened to 0.20 g/mi in 1984, a level that required the use of particulate filters. Mercedes introduced a Diesel Particulate Filter (DPF) system in 1984.

Prior to the widespread use of 3-way catalysts in the 1980s, the removal of catalytic converters was a common form of tampering. Tampering with the restrictors installed in fillpipes to prevent use of less expensive and higher octane leaded gasoline in catalyst-equipped vehicles was also widespread. I/M programs were instrumental in reducing this type of tampering in many states. Improved driveability of feedback controlled, 3-way catalyst equipped vehicles combined with the phase-down of leaded gasoline in the 1980s reduced the incidence of tampering in the absence of I/M programs. The exclusive use of unleaded gasoline combined with the high-energy ignition systems needed to comply with regulations limiting the frequency of emissions-related maintenance also improved the emissions performance of vehicles in customer service.

4.4 Low Emission Vehicle, Tier 1 and Tier 2 Standards

LEV I/Tier 1 – During the ten-year period from 1994 to 2003, the California, U.S., and Canadian emissions standards for light-duty vehicles became much more complicated. Throughout the entire period, there were multiple standard categories applicable to the same model year in California. Beginning in 1999, the multiple standard categories also applied in many other states. Starting in 2001, multiple standard categories applied in British Columbia also.

Beginning in 1994, the State of California began enforcing a "fleet average" HC standard that could be met by certifying vehicles to several different categories of what were called "Low Emission Vehicle" (LEV) standards. Under the first phase of the LEV standards (LEV I), fleet average non-methane organic gases (NMOG) for new light-duty vehicles had to be reduced from 0.25 g/mi in 1994 to 0.062 g/mi in 2003. Compliance was based on the sales-weighted average of several different standard categories ranging from 0.25 g/mi to 0.0 g/mi NMOG.

During the same period of time, the basic U.S. EPA regulations required compliance with "Tier 1" standards requiring light-duty vehicles to meet exhaust emissions standards of 0.25 g/mi non-methane HC, 3.4 g/mi CO, and 0.4 g/mi NOx. However, there was also a "National Low Emission Vehicle" (NLEV) program in place from 1999 through 2003 during which many vehicles certified to the California LEV standards were sold in other states.

The Diesel PM standard was tightened to 0.08 g/mi in 1994, a level that required invisible exhaust, nearly as low in particulate as a gasoline-fueled vehicle running on unleaded gasoline. Improved DPFs were developed that could comply with this standard. An optional 1.25 g/mi, 100,000 mile NOx standard allowed some Diesel models to be certified without NOx catalysts.

LEV II/Tier 2 – Beginning in 2004, California began enforcing "LEV II" standards, which required significantly lower NOx emissions than were required under the LEV I program. However, compliance is still based on fleet average NMOG. By 2010, passenger cars and the lightest trucks must achieve 0.035 g/mi NMOG at 50,000 miles. The corresponding average NOx emission level is just under 0.05 g/mi.

Also beginning in 2004, EPA and Canada required a phase-in of compliance with "Tier 2" standards. There are 10 separate standard "bins," which are combinations of HC, CO, and NOx standards. By 2007, the sales-weighted average emissions of passenger cars and light trucks up to 6,000 pounds test weight are required to achieve average emissions of 0.075 g/mi NMOG, 3.4 g/mi CO, and 0.05 g/mi NOx for 50,000 miles.

OBD – A phase-in of requirements for a second generation of on-board diagnostic systems (OBD II) also began in 1994. Essentially full compliance was required in the U.S. beginning in 1996 and in Canada beginning in 1998. The California Air Resources Board describes the capabilities of OBD II systems as follows:

> *On-board diagnostic capabilities are incorporated into the hardware and software of a vehicle's on-board computer to monitor virtually every component that can affect emission performance. Each component is checked by a diagnostic routine to verify that it is functioning properly. If a problem or malfunction is detected, the OBD II system illuminates a warning light on the vehicle instrument panel to alert the driver. This warning light will typically display the phrase "Check Engine" or "Service Engine Soon." The system will also store important information about the detected malfunction so that a repair technician can accurately find and fix the problem.*

The types of emissions-related defects that OBD systems must be capable of detecting include ignition system misfire, reduced catalyst efficiency, improper regulation of fuel:air ratio by the oxygen sensor(s) and feedback control system, inadequate EGR flow, vapor leaks in the fuel system, and improper or unexpected signals being generated by a variety of sensors (e.g., temperature and throttle position) used in the vehicle.

Although the OBD system isn't an emissions control device per se, it is highly effective in identifying emissions-related defects that might otherwise go undetected. It's the equivalent of subjecting a vehicle to I/M on a daily basis. Voluntary repairs made by owners contribute to lower emissions in customer service. In conjunction with an I/M program, the OBD system ensures that vehicles with emissions-related defects are efficiently identified.

I/M Issues – The more advanced emissions control systems used on LEV I, LEV II, Tier 1, and Tier 2 vehicles are less prone to emissions deterioration for at least two reasons. First, refinement of fuel metering and emissions control systems has progressed to the point that almost all vehicles have excellent driveability and both owners and repair technicians have less incentive to tamper with vehicles. Second, the OBD systems deter tampering and encourage routine maintenance by illuminating a malfunction indicator light when tampering or an emissions-related maintenance problem is detected.

Notwithstanding lower level of emissions deterioration on an absolute basis, late-model vehicles experience relatively high rates of deterioration on a percentage basis because they start out so close to zero emissions. In addition, as they age, 2004 and later model year vehicles still have the potential to become gross emitters. Higher catalyst efficiency is the primary reason why 2004 and later models meet lower standards; when serious maintenance problems develop later in life (e.g., misfire), deterioration of the catalysts can result in emissions that are just as high as those from older technology vehicles.

4.5 Alternative Technologies and Fuels

The potential for the future use of alternative technologies and alternative fuels could conceivably affect the need for an I/M program. For example, conversion to hydrogen powered fuel cell vehicles or battery-electric vehicles would eliminate CAC emissions altogether. However, within the 20-year time horizon considered in the current study, there is unlikely to be any significant transition to alternative technologies or fuels that would not be subject to emissions deterioration.

In the light-duty vehicle fleet, only two alternatives to the spark ignition engines using gasoline or ethanol-gasoline blends are projected to make significant inroads in the next 20 years: Diesel engines and hybrid drive systems using the combination of a spark ignition engine and a battery-powered electric motor. Diesel-powered vehicles and hybrid vehicles will both require emissions control systems requiring maintenance in customer service.

A detailed analysis of alternative technologies and fuels is contained in Appendix B.

5. How I/M Affects Light-Duty Vehicle Emissions

Task 3 of the scope of work required Sierra to provide projections of emissions from light-duty vehicles for the following scenarios:

1. No I/M program after December 31, 2011;
2. Retaining the current I/M program design, policies, and standards from January 1, 2012 to December 31, 2020; and
3. Implementing a new, revised I/M program (or multiple program options) with the best possible combination of low delivery cost and maximum yield of emissions reductions

A variety of techniques have been previously used to estimate the emissions benefit associated with the AirCare program, including emissions models, the difference in measured emissions before and after the repair of vehicles that failed an initial test, and data collected using remote sensing devices comparing emissions of vehicles known to have been through the AirCare program with vehicles that were apparently registered outside the program area.

The most recent analysis of program benefits by the AirCare program staff was based on the measured effectiveness of repairs performed to vehicles that initially failed the inspection combined with reductions associated with vehicles that failed the test and were apparently retired from service or sold outside the area. On an impact-weighted basis (HC+NOx+CO/7), the reductions calculated for the program were 11.7% in 2007 and 10.6% in 2008.

As we understand how the staff calculation was done, the reductions associated with vehicles no longer being used within the area did not account for the fact that total travel volume is usually conserved when some vehicles are scrapped or sold outside the region. However, as described in more detail below, there are other factors contributing to emissions reductions from the AirCare program that the staff analysis did not take into account.

5.1 Estimating I/M Benefits

Conceptually, the benefits of a specific I/M program might seem easy to determine. However, accurate data on benefits are generally unavailable. In all but a few cases, estimates of program benefits are improperly made and/or based on inaccurate data. Estimation of the emissions reductions for a particular I/M program are complicated by the factors summarized below.

1. Short Test Accuracy – To varying degrees, the test procedures used in particular I/M programs are not representative of the full range of vehicle operation in

customer service. The emission reduction observed when a vehicle that initially fails eventually passes a retest may not reflect the true emission reduction in customer service.[18]

2. Post-I/M Deterioration – The immediate benefits of repairing a failed vehicle do not account for post-I/M deterioration that can be expected to occur before the next I/M test.

3. Residual Benefits – On average, there are residual benefits from the previous I/M test that still exist at the time of the subsequent I/M test. Most analyses exclude these benefits because they are difficult to estimate or are unrecognized.

4. Pre-Inspection Repairs and Tampering Deterrence – The benefits of an I/M program are clearly not limited to the repair of defects identified during initial tests. Most programs encourage motorists to correct obvious emissions-related defects before they obtain an initial test. To the extent motorists do this, and to the extent that the existence of the program deters motorists from tampering with emissions control systems, there are real benefits that are not measured at inspection stations.

5. Falsified Test Results – Although many decentralized inspection stations do quality work, covert auditing indicates that "clean piping,"[19] falsified gas cap checks, or falsified or incorrect visual inspection results occur at some stations, which causes repair effectiveness to be overstated.[20]

6. OBD Systems "Not Ready" – To minimize customer inconvenience, most I/M programs allow 1996 and newer vehicles to "pass" a check of the OBD system even if one to three monitors (depending on the program) are "not ready" (indicating that the vehicle has not been driven under the conditions necessary for the OBD system to check for a specific type of defect). This makes it possible for a vehicle to go from "failing" to "passing" status when the battery is disconnected to "clear" fault codes even when no repair has been done. Since most programs do not perform tailpipe tests on vehicles receiving OBD checks, the reduction in emissions associated with passing an OBD check after initially failing is not recorded. Quantifying the benefits of this element of the program can introduce significant uncertainty.

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[18] This is especially a problem for programs that test emissions at idle; however, it is also a problem for programs using more representative test procedures such as the IM240 dynamometer test when a "fast pass" algorithm is used to reduce the time required to test vehicles with relatively low emissions. Because of differences in preconditioning and driving cycle, results before and after repair obtained with a fast past algorithm in place cannot be directly compared.

[19] "Clean piping" is the term used to describe the testing of a known low emission vehicle in place of a vehicle with high emissions that should have been tested.

[20] Covert auditing of the California "Smog Check" program has shown that test results on vehicles with emissions-related defects are falsified approximately 20% of the time. In one study involving over 800 covert audits, the average CO emissions reduction claimed for the falsified test results was 66% when, in fact, there was no reduction.

7. Evaporative Emissions are Not Measured – The correction of evaporative emissions defects identified through the use of gas cap testers, evap system pressure testing, and visual inspections is not quantified by an actual emissions measurement.

8. Compliance Rate Uncertainty – Uncertainty in the benefits of an I/M program is caused by uncertainty regarding (1) the fate of “disappearing vehicles” (vehicles that fail an initial test and never receive a passing test), (2) the significance of unregistered vehicles, and (3) the significance of vehicles registered outside the I/M area that are actually garaged and used in the I/M area.

Table 12 summarizes the limitations of “in-program” data for determining the emissions reductions being achieved by an I/M program and indicates what the usual effect is on estimates of the emissions reductions being achieved by the program.

Table 12
Limitations of “In-Program” Data for Estimating the Benefits of an I/M Program

Limitation		Usual Effect on Estimated Benefits
1.	Short Test Does Not Represent Typical Customer Service	Exaggerates Benefits
2.	Post-I/M Deterioration Not Easily Accounted For	Exaggerates Benefits
3.	Residual Benefits Not Easily Accounted For	Understates Benefits
4.	Pre-Inspection Maintenance and Tampering Deterrence Not Easily Accounted For	Understates Benefits
5.	Falsified Test Results in Decentralized Programs	Exaggerates Benefits
6.	OBD “Not Ready” Allowed	Exaggerates Benefits
7.	No Evaporative Emissions Measurement	Understates Benefits
8.	Compliance Rate Uncertainty	Exaggerates Benefits

Because of the difficulties listed above, an accurate measurement of the emissions reduction associated with an I/M program is extremely difficult and cannot be based on “in-program” data. The U.S. EPA therefore issued a Guidance Document which recommends that states evaluate the effectiveness of their programs using what is commonly referred to as the “benchmark method.”[21] Under the benchmark method, the fully preconditioned IM240 (or IM147) emissions of a large, random sample of vehicles going through one I/M program are compared to the fully preconditioned IM240 (or IM147) emissions of vehicles going through the Phoenix, Arizona program (in which a random sample of vehicles are subjected to fully preconditioned IM147 tests). This would enable EPA to determine whether a particular program meets the U.S. statutory requirements for enhanced I/M, which are not related to a specific emissions reduction percentage but are instead related to achieving the same degree of control provided by a program with the characteristics listed below.

- Centralized Network Type
- Annual Inspection Frequency
- 1968 and Later Model Years Included
- LDGV, LDGT1, LDGT2 Vehicle Types Included
- Idle Emission Test on 1968-1980 Models
- Idle/2500 Emission Test on 1981-1985 Models
- IM240 Emissions Test on 1986 and Later Models
- Evaporative System Pressure Test on 1983 and Later Models
- Evaporative System Purge Test on 1986 and Later Models
- Visual Check of Catalyst and Fuel Inlet on 1984 and Later Models
- Pre-1981 “Stringency” (failure rate) of 20%
- Pre-1981 Waiver Rate of 3%
- Post-1980 Waiver Rate of 3%
- Compliance Rate of 96%

(The above definition of “enhanced I/M” was developed prior to the use of OBD systems and EPA now considers OBD-based tests to be equally effective to IM240 with purge and pressure testing.) Although the Phoenix, Arizona program differs somewhat from the above-listed characteristics, it is considered close enough to serve as the benchmark program.

Because the recommended method for program evaluation does not actually require the measurement of the true emissions reductions being achieved, U.S. EPA relies on its “MOBILE6” computer model to estimate the theoretical benefits of various I/M

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[21] EPA has also stated that, at least conceptually, program evaluations can be based on remote sensing test results. However, the EPA guidance does not address specifically how the substantial practical problems associated with the use of remote sensing can or should be addressed. Foremost among those problems is that remote sensing produces significantly different results for the same vehicle when it is measured at different times using different gasoline, or at different locations, or under different levels of traffic congestion that affect how the vehicle is being driven at the same location. Because site-to-site variations in remote sensing test results can exceed the difference in emissions associated with an I/M program, it is not possible to simply compare the results obtained in an area with an I/M program to the results obtained in an area without an I/M program and know that the difference is the effect of the I/M program. For the same reason, it is not possible to use remote sensing to measure differences in emissions before and after I/M unless the vehicle operating conditions and gasoline specifications are exactly the same.

programs. A "discount" is supposed to be applied to the results produced by the model to account for the differences between a specific program and the "benchmark" program. (As a practical matter, this adjustment is invariably not made. As discussed elsewhere, EPA has effectively abdicated its responsibility for I/M program evaluation and enforcement.)

When MOBILE6 is used to evaluate the AirCare program, the estimated emissions reductions for 2010 are 13.0% for HC, 15.8% for CO, and 14.2% for NOx. Although these are greater reductions than estimated by the AirCare staff, they understate the actual benefits of the program, as is explained in more detail below.

5.2 Comparison of MOBILE with Actual Test Results in California

An indication of how the MOBILE model understates the benefits of I/M programs is available from a comparison of MOBILE estimates for the California I/M program with the results of a special study conducted in California. The "California I/M Pilot Project" involved the testing and repair of hundreds of vehicles by qualified technicians working for the State of California. That program determined that the theoretical benefits of an enhanced I/M program would be emissions reductions of 40-45% for HC, 40% for CO, and 25-30% for NOx for pre-OBD vehicles.[22] Table 13 compares these theoretical benefits to benefits estimated by the MOBILE model for a primarily pre-OBD fleet.

Table 13
Enhanced I/M Reductions for Pre-OBD Vehicles
California "Pilot Project" vs. MOBILE Model

	HC	CO	NOx
California Pilot Project	42.5%	40.0%	27.5%
MOBILE Model Estimate	16.4%	22.6%	15.6%
Ratio Theoretical/MOBILE	2.59	1.77	1.76

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[22] T.C. Austin and P.L. Heirigs, "The Effectiveness of IM240 Testing, ASM Testing, and Remote Sensing Based on the California I/M Pilot Project," Sierra Research, Inc. presentation at the 16th North American Motor Vehicle Emissions Control Conference, March 1995.

5.3 MOBILE Model Estimates for the OBD Fleet

As older technology vehicles are replaced with newer vehicles certified to meet more stringent emissions standards, the MOBILE model estimates larger I/M benefits on a percentage basis, but much smaller benefits on a total mass basis. Table 14 shows that the effectiveness of I/M based on MOBILE6.2C for vehicles meeting the stringent Tier 2 standards. Incremental reductions range from 31% for HC to 46% for NOx. Given the dramatically lower emissions resulting from the Tier 2 standards, the HC reduction is only 0.054 g/km. However, based on our review of the methodology EPA is using to estimate no-I/M emissions, the agency has underestimated the percentage of vehicles that will fail to meet the standards in the absence of I/M.

Table 14
Light-Duty Vehicle Emissions Reductions Due to I/M Applied to Tier 2 Vehicles Based on MOBILE6.2C

	HC*	CO	NOx
MOBILE6.2C, Tier 2 Vehicles No I/M	0.174 g/km	2.44 g/km	0.131 g/km
MOBILE6.2C, Tier 2 Vehicles With I/M	0.120 g/km	1.53 g/km	0.071 g/km
MOBILE6.2C, Change Due to I/M, g/km	**-0.054 g/km**	**-0.91 g/km**	**-0.060 g/km**
MOBILE6.2C, Change Due to I/M, percent	-31.0%	-37.3%	-45.8%

*HC emissions include exhaust, evaporative, and crankcase.

5.4 Development of Alternative No-I/M Emission Factors

The MOBILE model estimates emissions from vehicles in customer service based on several assumptions, which include the following:

1. The rate at which emissions-related defects will develop as vehicles age;
2. The increase in emissions associated with the defects;
3. The fraction of defective vehicles that will be voluntarily repaired in the absence of an I/M program;
4. The fraction of defective vehicles that will be repaired with an I/M program in place; and
5. The effectiveness of repairs to defective vehicles.

The model assumes that vehicles without emissions-related defects (“normal emitters”) will have emissions close to the standards they were certified to meet, but will deteriorate slightly as they age. Repaired vehicles are assumed to have emissions no higher than 1.5 times the standard. In contrast, “high emitters” are assumed to have a level of emissions at least two times the 50,000 mile HC or NOx standards and at least three times the 50,000 mile CO standard. Surprisingly, the emissions from high emitters are assumed to independent of the age of the vehicle.

The average emission rates for Tier 1 and Tier 2 "high emitters" are not based on data from high mileage vehicles in actual use because no such data were available at the time the model was developed. Instead, the emission rates for "high emitters" are based on estimates of the type of defects that will occur and what the effect on emissions will be. Certain types of defects are assumed to increase emissions by an amount that is proportional to the standards a vehicle was originally certified to meet. Other types of defects are not assumed to be proportional to the standards. As shown below, the net effect of the assumptions is that Tier 1 and Tier 2 vehicles with emissions-related defects are assumed to have relatively low emissions on average. The fraction of high emitters that will exist in the fleet, with and without I/M, are also estimates made without the benefit of any data from vehicles in actual use. A peer review of the assumptions on which the Tier 1 and Tier 2 emission estimates are based concluded that there was a high level of uncertainty.

Table 15 shows how the emission rates assumed for "high emitters" incorporated in MOBILE6.2 compare to uncontrolled vehicles and the average emissions of the fleet. The HC and NOx emission rates are presented in EPA report.[23] The CO rates are calculated from "start" and "running" emissions presented in another EPA report.[24]

Table 15
Light-Duty Vehicle Exhaust Emissions Rates In MOBILE6.2C

	HC	CO	NOx
Pre-Control Vehicles (0 miles)	4.9 g/km	50.0 g/km	2.77 g/km
Tier 2 Vehicles With I/M	0.06 g/km	1.53 g/km	0.071 g/km
"High Emitters"	**0.76 g/km**	**23.9 g/km**	**0.43 g/km**

As can be seen by comparing the high emitter emission rates to the emission rates for pre-control vehicles, the average Tier 2 vehicle with emissions-related defects is still assumed to have 84% lower HC exhaust emissions than a vehicle without emission controls. In contrast, a vehicle operating with persistent ignition misfire is like to emit more than 10 times as much HC as assumed for the average Tier 2 vehicle with emissions-related defects. In order for the high emitter rates to be accurate, there can be very few vehicles in the fleet with such serious emissions problems.

Because of the uncertainty associated with the assumptions incorporated in MOBILE, an alternative estimate of emissions in the absence of an I/M program has been developed by comparing the rate of emissions-related defects assumed to occur in the MOBILE model

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[23] John W. Koupal and Edward L. Glover, "Determination of NOx and HC Basic Emission Rates, OBD and I/M Effects for Tier 1 and later LDVs and LDTs," Final Report M6.EXH.007, Assessment and Standards Division, Office of Transportation and Air Quality, U.S. Environmental Protection Agency, Report No. EPA420-R-01-056, November 2001.

[24] Edward L. Glover, et al., "Update to the Determination of CO Basic Emission Rates, OBD and I/M Effects for Tier 1 and Later LDVs and LDTs," M6.EXH.012, Assessment and Modeling Division, Office of Transportation and Air Quality, U.S. Environmental Protection Agency, Report No. EPA420-R-03-011, September 2003.

with the actual rate of emissions-related defects observed during roadside inspections of randomly selected vehicles.[25] The California Bureau of Automotive Repair provided Sierra with data collected during the inspections of tens of thousands of vehicles selected at roadblocks set up by the California Highway Patrol. The tests were conducted from February 2003 to November 2009. Our analysis focused on the 1996 to 1999 model year vehicles, which were the oldest Tier 1 compliant vehicles equipped with OBD systems. The average age of these vehicles at the time they were inspected was 10.16 years. The data analyzed included exhaust emissions measured using portable dynamometers, OBD scan results, visual inspection results, and results of several evaporative emissions tests. The results of the analysis are summarized in Table 16.

Table 16
Emissions-Related Defects in the Light-Duty Vehicle Fleet
MOBILE6.2 Assumptions vs. California Roadside Data
(10-Year Old Vehicles)

	MOBILE No-I/M	MOBILE w/I/M	Roadside Data
Tampering	0.0%	0.0%	3.4%
Evaporative Failures	3.0%	1.6%	6.2%
Exhaust Failures	41.8%*	8.7%	31.1%**
Evap + Exhaust Fail	43.5%	10.2%	34.9%

*Calculated from NOx failure rate adjusted to account for HC and CO failures with NOx pass
**Calculated from overall failure rate and adjusted to account for evaporative only failures

As shown in the table, the roadside failure rate is more than three times what is assumed in the MOBILE6.2 model for an area with an I/M program. As noted earlier, previous studies have shown that California's decentralized I/M program achieves only about 50% of the benefit that is expected from the accurate inspection and repair of vehicles. For that fraction of the fleet equipped with OBD systems, the performance of the California program is probably better. Assuming that the California I/M program is detecting and correcting defects in two-thirds of the OBD-equipped vehicles, the rate of defects observed at the roadside for 10-year old vehicles would be 21% if the no-I/M defect rates imbedded in the MOBILE mode are correct. The actual defect rate of 34.9% is 66% higher.

The 3.4% tampering rate shown in Table 16 is another indication of problems associated with the assumptions incorporated in the MOBILE model. According to the MOBILE6 documentation,

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[25] The original plan for the development of improved no-I/M emission factors was to analyze data from the Arizona I/M program comparing the emissions of vehicles entering the program from non-I/M areas to the emissions of vehicles that have previously been subject to I/M. Having assisted EPA in the development of the data set, we expected that it would be available for further analysis. We knew that the data were being collected specifically for estimating how the emissions from vehicles not subject to I/M compare to the emissions of vehicles subject to I/M. However, discussions with EPA staff indicated that the Arizona data were not actually used in the development MOBILE6.2 I/M benefit estimates and a copy of the data set was not available.

> *For the 1996 and later model years, there is assumed to be no tampering in the fleet. This assumption was made because strong engineering reasons and anecdotal evidence suggests that deliberate tampering of emission control devices is not common on today's late model vehicles. This is because the reasons for tampering, such as the ability to misfuel, perceived improved performance and perceived cost savings on vehicle operation do not exist anymore. Also, the advent of OBD systems should also discourage tampering, because the immediate result of tampering is an OBD warning light.*

In contrast to the above assumption, roadside inspection results from California indicate that a significant rate of tampering is still occurring, even in a state with an I/M program. In the absence of California's I/M program, it would be expected that the tampering rate would be substantially higher.

There are two reasons why a significant amount of tampering can be expected in the absence of an I/M program. First, contrary to the assumptions used by EPA in developing MOBILE6.2, many vehicle owners do believe there will be a performance benefit associated with certain types of tampering, including the removal of catalytic converters to reduce exhaust system backpressure. Even with many areas subject to I/M, aftermarket exhaust system manufacturers are already selling non-catalyst exhaust systems for late model vehicles that are popular with owners interested in improving performance. Second, data from within the AirCare program make it clear that tampering increases significantly in the absence of requirements for emissions control devices to be left in place. The catalyst removal rate for pre-1988 models is approximately 6% even though the vehicles are still required to pass AirCare emissions test. The fact that pre-1988 models are not failed for a missing catalyst has clearly induced many owners to forego the cost of a catalyst-equipped exhaust system when replacement of the original system is required.

For the reasons described above, Sierra believes that the actual benefits of continuing an effective I/M program may be twice those estimated by MOBILE6.2C. We believe the "with I/M" emission estimates are reasonable, but the defect rates and the emissions from vehicles with emissions-related defects used in the model clearly need to be improved.

Because of the concern regarding the MOBILE6.2C estimates of emissions in the absence of an I/M program, our analysis has been conducted using two different assumptions for the no-I/M case. In one case, we used estimates produced by the MOBILE model. In the other case, we increased emissions for the no-I/M case to reflect doubling of the difference between no-I/M and with I/M for exhaust emissions for Tier 1 and Tier 2 vehicles. (It should be noted that we have not changed the emission rates assumed for high emitters, which is another area of uncertainty.) Table 17 shows how the results are affected by the difference in assumptions.

Table 17
Annual Light-Duty Vehicle Emissions in the LFV With and Without Current AirCare Program

Year and Pollutant	No-I/M Per MOBILE	No-I/M Revised Model	With I/M	Emission Reduction Per MOBILE		Emission Reduction Revised Model	
	tonnes	tonnes	tonnes	tonnes	%	tonnes	%
2010							
VOC	12,744	13,653	11,092	1,653	13.0%	2,562	18.8%
CO	189,220	206,947	159,237	29,982	15.8%	47,710	23.1%
NOx	11,966	13,010	10,268	1,699	14.2%	2,743	21.1%
Impact-Weighted*	51,742	56,228	44,107	**7,635**	**14.8%**	**12,120**	**21.6%**
2020							
VOC	6,995	8,600	5,208	1,787	25.6%	3,393	39.4%
CO	157,183	187,791	126,527	30,657	19.5%	61,264	32.6%
NOx	6,430	8,372	4,489	1,942	30.2%	3,883	46.4%
Impact-Weighted	35,880	43,800	27,772	**8,109**	**22.6%**	**16,028**	**36.6%**

*VOC+(CO/7)+NOx

Based on MOBILE6.2C, the AirCare program will reduce impact-weighted light-duty vehicle emissions by 7,635 tonnes in 2010, which is a 14.8% reduction from the model's estimates of emissions in the absence of an I/M program. Assuming twice the rate of emissions-related defects without I/M, our alternative estimate of the impact-weighted benefits increases to 12,120 tonnes, a 21.6% reduction.

It may seem counter intuitive, but the MOBILE model actually projects that the impact-weighted emission reductions achieved by the program will increase from 7,635 tonnes per year to 8,109 tonnes per year by 2020. This is projected to occur despite the fact that total impact-weighted emissions from the fleet are projected to decrease by 37% as newer, cleaner vehicles replace older vehicles that are being retired from service. The increase in the projected benefits of the AirCare program is due to the combination of two factors: (1) the projected growth in vehicle travel, and (2) the projected increase in the effectiveness of I/M for OBD-equipped vehicles meeting more stringent emissions standards.

When no-I/M emissions are adjusted to reflect a higher rate of emissions-related defects, the benefit of I/M on impact-weighted emissions in 2020 increases to 16,028 tonnes, a 36.6% reduction.

The estimates shown in Table 17 are based on the current version of the AirCare program. A later section of this report contains estimates of how changes in the design of the AirCare program are expected to affect future emission levels.

5.5 Calculating Cost/Effectiveness

The total cost of an I/M program is routinely limited to the cost for testing vehicles, the cost for oversight and enforcement by the agency administering the program, and the cost for repairing vehicles that fail the test. (These are the costs that have previously been used to estimate the cost/effectiveness of the AirCare program.) As noted above, there are benefits associated with pre-inspection maintenance that have not been accounted for by AirCare staff, but the cost of pre-inspection maintenance has not been estimated either. Arguably, the value of motorists' time spent on compliance with program requirements should also be taken into account.

In its most recent evaluation of the AirCare program,[26] program staff reported a 13% failure rate for 881,323 vehicles tested in 2007 and 2008. About 80% of the failed vehicles returned for re-inspection after repairs. The average repair cost per vehicle was reported to be $428 in 2008. About 20% of the failed vehicles apparently were retired from service or sold outside of the program area. (There is no estimate available for the cost associated with the removal of those vehicles.)

On an impact-weighted basis, the reduction in emissions from the documented repairs was reported to be 7.1% in 2007 and 6.3% in 2008. Additional benefits of 4.6% in 2007 and 4.3% in 2008 were estimated for the 20% of the failed vehicles that were apparently removed from service or sold outside the area. (The relatively greater benefit per vehicle is based on the fact that the AirCare staff assumed the emissions from these vehicles would be removed from the inventory without being replaced by additional travel by other vehicles, an assumption that we believe overstates the true benefits.)

In contrast to the estimates by AirCare staff, the estimates of the effectiveness of the AirCare program shown in Table 17 account for pre-inspection maintenance and vehicle retirement by calculating program benefits from the difference of total emissions with and without an I/M program using the MOBILE model and a modified no-I/M version of MOBILE. (Implicit in this approach is that any vehicles retired from service or sold outside the area are replaced by other vehicles.) However, it is clear from the failure rate observed in the AirCare program that many of the vehicles that the model projects to have emissions-related defects in the absence of I/M are not failing in the inspection lanes. This should not be surprising. Most owners understand that they will fail the test and incur additional costs if they show up for testing with a vehicle that has an obvious emissions-related problem. Especially for owners of vehicles with OBD systems (which includes many pre-1998 models), there is a significant incentive to obtain repairs of vehicles with illuminated malfunction indicator lights before the initial inspection. The process we use for estimating the cost of this pre-inspection maintenance is to assume 18% new failures every two years. (This is twice the biennial increase in failures observed in the California program, which we assume to be 50% effective.) The following equation shows our calculation of the total cost per inspected vehicle:

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[26] S.J. Stewart, et al., "AirCare - Results and Observations in 2007 and 2008," Pacific Vehicle Testing Technologies, 2009.

$$\begin{aligned}\text{Cost/Vehicle} &= \$45 + (0.104 \times \$23) + (0.18 \times \$428) - (0.011 \times \$3{,}000)\\ &= \$45 + \$1.35 + \$77 - \$33\\ &= \$90 \text{ (over two years)}\end{aligned}$$

Where: $45 is the initial inspection cost incurred in two years

0.104 is the fraction of vehicles that return for a re-inspection

$23 is the re-inspection cost

0.18 is the estimated fraction of the inspected vehicles requiring pre-inspection maintenance or maintenance after failing

$428 is the average repair cost

(0.011 × $3,000) is the fuel cost savings over 2 years[27]

Based on 881,323 vehicles tested in 2007 and 2008, total program cost is estimated at $39.7 million per year. With a light-duty vehicle growth rate estimated at 1.25% per year, the cost projection for 2010 is $41 million for 454,562 vehicles.[28] Based on the 12,120 tonne impact-weight emission reduction from Table 17, the cost-effectiveness ratio is $3,383 per tonne. Based on the unadjusted MOBILE model estimate of a 7,635 tonne reduction, the cost-effectiveness ratio is $5,370 per tonne.

Related economic impacts include the fact that the per vehicle repair costs translate into approximately $35 million in revenue for the automotive repair industry. The AirCare program also employs approximately 160 individuals.

New vehicle sales in the AirCare program area are also affected. As noted above, about 20 percent of the vehicles failing an AirCare test never return for reinspection. These vehicles are presumed to be either retired from service or sold outside of the area subject to the program. There are approximately 11,500 vehicles per year in this category.

Based on a survey of participants of vehicle scrappage programs conducted in California[29], approximately 60% of scrapped vehicles are replaced with the purchase of another vehicle by the household that owned the vehicle being scrapped. (About one-third of the owners simply drove another vehicle they already owned more and a small percent used an alternative form of transportation.) Assuming the same ratio applies to vehicles that failed to return for reinspection, approximately 7,000 additional vehicle

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[27] Assumes approximately 10,000 miles per year, 28 mpg, and $1.10 per litre.

[28] By 2020, annual cost would increase to approximately $47.6 million and the average cost for 2011 through 2020 would be approximately $45 million.

[29] "Report to the California Legislature, Accelerated Light-Duty Vehicle Retirement Program," California Air Resources Board, July 2004.

sales would be associated with the number of vehicles prematurely removed from service due to the AirCare program.

Many owners of vehicles being retired from service would be likely to purchase a used vehicle; however, the increase in vehicle sales resulting from vehicles being prematurely removed from service ultimately results in increased sales of new vehicles. It should be noted, however, that there is not a one-for-one impact on new vehicle sales because vehicles being voluntarily removed from service have, on average, a relatively short remaining life compared to the life of a new vehicle. According to the MOBILE model, the average life of a new passenger car is approximately 14 years. If the remaining life of a vehicle voluntarily removed from service is 1.4 years, then the long term effect on new vehicle sales is about 10% of the number of vehicles being removed from service, 700 in this case.

At an average new vehicle purchase price of $30,000[30], there would be about $21 million in additional new vehicle sales per year associated with the AirCare program. This is considered a conservative estimate because of the relatively short remaining life assumed for vehicles that are voluntarily removed from service. A more detail survey would be needed to refine this number. Further analysis of this factor may be appropriate because, in addition to reducing emissions, an increase in fleet turnover contributes to increased vehicle safety and fuel economy.

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[30] According to "New Motor Vehicle Sales," published by Statistics Canada in December 2009, the average new car price in British Columbia was $28,000 in 2009. Accounting for light-duty truck prices, the average price of a new vehicle subject to the AirCare program would be in excess of $30,000.

6. Trends in I/M Testing Programs and Procedures

To ensure the maintenance of emissions control systems in customer service, the State of California implemented the first emissions-related vehicle inspection program on a change-of-ownership basis in the 1960s. Since then, dozens of other states and two Canadian provinces have also implemented inspection programs that are intended to minimize tampering with emissions control systems and ensure that other emissions-related defects are identified and corrected.

In addition to the two I/M programs operating in Canada, I/M programs are currently operating in 32 states and the District of Columbia. As summarized in this section, there are substantial differences between the programs currently in operation with respect to network type, inspection frequency, range of model years included, test procedures, and emissions standards. In several states, there are significant differences in the I/M programs operating in different regions of the state.

As described in more detail below, there is a trend toward reduced use of exhaust emissions testing and visual inspections and increased reliance on OBD system testing in U.S. I/M programs. However, there are significant differences between programs with respect to the OBD test criteria and the repair requirements for vehicles that fail the test.

Because of the program differences that exist, there are substantial differences in the effectiveness of specific programs in reducing vehicle emissions. It is important to note that the differences in program effectiveness are undocumented. The benefits of most programs are estimated by EPA’s MOBILE model rather than independent data on the actual effectiveness of a particular program. Since the mid-1990s, EPA has essentially abdicated its responsibility for overseeing and evaluating the effectiveness of programs required under the Clean Air Act. As a result, there are programs we believe to be almost totally ineffective for which a state is claiming significant emissions reductions. (At the other end of the spectrum, as described earlier, the most effective programs are likely achieving benefits in excess of those estimated by the MOBILE model.)

To put the U.S. I/M programs into perspective, the following sub-section describes the evolution and subsequent devolution of I/M in the U.S.

6.1 Federal I/M Requirements

The Clean Air Act Amendments of 1970 required all states to develop emission control measures sufficient to demonstrate attainment with the National Ambient Air Quality Standards (NAAQS). The Clean Air Act Amendments of 1977 modified the compliance deadlines for attaining the NAAQS and required EPA to provide information to states regarding how motor vehicle inspection and maintenance programs could be used to reduce emissions. It also required state air quality plans to provide “to the extent necessary and practicable, for periodic inspection and testing of motor vehicles to enforce compliance with applicable emission standards.” In response to this somewhat general requirement, many I/M programs were adopted throughout the U.S.

The 1990 Clean Air Act Amendments specified more detailed requirements for I/M programs and required EPA to promulgate regulations defining the minimum acceptable specifications for "basic" and "enhanced" I/M programs (final rule, dated November 5, 1992). States with "marginal" or "moderate" ozone nonattainment areas, or moderate CO nonattainment areas,[31] were allowed to implement only basic I/M programs, whereas states with areas within ozone transport regions, or with "serious" or "severe" ozone nonattainment areas meeting certain population criteria, were required to implement enhanced I/M.[32]

Enhanced I/M was defined as a program yielding emission reductions equivalent to a centralized[33] I/M program using a transient dynamometer test (i.e., IM240) and functional testing of the evaporative emissions control system (pressure and purge) on late-model cars and trucks. As of 2010, based on changes in the Consumer Price Index (CPI) since 1989, enhanced I/M also requires the expenditure of at least $779 ($450 adjusted for CPI changes from 1989 to the preceding year) on emissions-related repairs to qualify for a waiver, as well as other program elements. Under EPA's initial regulations, decentralized[34] programs were assigned only 50% of the emissions reductions from centralized I/M programs unless states could produce evidence to the contrary.

EPA's plans for requiring widespread use of centralized programs went awry in mid-1994, after startup problems occurred in some states when centralized IM240 programs were brought on line. These problems fueled intense and widespread political opposition to centralized I/M with transient dynamometer testing. Passage of the National Highway System Designation Act of 1995 prohibited EPA from requiring IM240 testing or from automatically discounting emission reduction credits claimed by states for decentralized, test-and-repair I/M programs. A number of states subsequently claimed greater than the 50% of centralized emission reduction credits for their decentralized I/M programs.

EPA's initial response to losing the authority to force states to use centralized I/M programs (by discounting decentralized I/M program benefits by 50%) was to adopt program evaluation requirements that would ultimately force states to upgrade ineffective programs for which they were claiming benefits equivalent to centralized programs with IM240 and functional evaporative emissions testing.

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[31] Those with design values of no more than 12.7 parts per million (ppm).

[32] Enhanced I/M that focused on CO emissions only (i.e., with no testing of the evaporative emission control system) was required in CO nonattainment areas with design values of >12.7 ppm at the time of classification. This included some moderate and all serious CO nonattainment areas.

[33] Centralized programs are those where the inspection and repair functions are entirely separate; all inspections are performed at government- or contractor-operated inspection facilities.

[34] Decentralized programs are those where inspection and repair functions are performed at private repair facilities (e.g., automobile repair shops or dealerships). These programs can also include a "test-only" element in which the inspection and repair functions are entirely separate for some fraction of the fleet, but the inspections are still conducted at private facilities.

Under the guidelines, states requiring enhanced programs are to determine program effectiveness on a biennial basis through the use of test data (the test method is unspecified) obtained from a minimum of 0.1% of vehicles subject to inspection coupled with "a sound evaluation methodology capable of providing accurate information about the overall effectiveness of an I/M program."

An EPA memo dated September 30, 1998, to "I/M Stakeholders" authorizes the use of three possible program evaluation methodologies: (1) the "Sierra Research Method," which relies on statistical sampling and analysis of state I/M program data, modeling data, and correlations compared to a "benchmark" centralized I/M program; (2) the VMAS[35] method, which relies on less costly test equipment to simulate the mass emissions sampling done in the IM240 test using a random sample of vehicles; and (3) the RG240 method, which, like the VMAS method, uses a lower-cost emissions measurement system to test a random sample of vehicles. These latter two methods have been judged by EPA to be equivalent to the IM240 test, with regard to their use as a program evaluation tool. The random sample recruitment and benchmark comparison provisions of the Sierra Research Method would, however, also apply to the VMAS and RG240 methods.

Supplementing the original program evaluation guidance, EPA released guidance in July 2002 that addressed using remote sensing measurements to evaluate I/M program effectiveness. The remote sensing guidance suffers from a number of flaws, which raises the question of whether its contents truly reflect a "sound evaluation methodology." The guidance appears to at least partially address this issue by suggesting that states consult with EPA in devising the specific remote sensing based approach to be used in evaluating their programs. Nonetheless, its release opened the door for less rigorous program evaluations. EPA's program evaluation requirements are further muddled by draft guidance circulated in 2001 for using in-program data (i.e., actual test data) for program evaluation. Also in 2001, EPA amended its I/M regulations to allow states to substitute OBD testing for IM240 and functional evaporative emissions testing for 1996 and newer vehicles.[36]

Several states have used the Sierra Research Method for their evaluations; however, various changes have been introduced to fit the available data or make it easier to implement. Additionally, the majority of I/M tests are currently OBDII tests where tailpipe emissions measurements are not taken, making the use of in-program data for evaluation more problematic. EPA has not updated any of the guidance documents to address this shortcoming. The methods used by each state have varied considerably depending on program design, available resources for the required analyses, political considerations, and other factors unique to each state. At least two states (Georgia and Colorado) use remote sensing measurements for program evaluations.

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[35] "VMAS" is an exhaust flow measurement system developed by Sensors, Inc, utilizing proprietary technology together with a transient drive cycle to calculate grams/mile emissions without using CVS equipment.

[36] Federal Register / Vol. 66, No. 66 / Thursday, April 5, 2001.

Other states appear to be ignoring the EPA program evaluation requirements. There is no single clearinghouse for the receipt or archiving of evaluation reports submitted by states since the reports are submitted and reviewed by the regional EPA offices, and EPA does not maintain a list of states that have failed to comply with this program requirement. EPA has left the follow-up for missing reports in the hands of the individual regions, and the degree of enforcement of these requirements by each region is inconsistent.

The lack of enforcement against non-complying states, coupled with EPA's apparent acceptance of less than rigorous program evaluations, raises substantial questions about the entire process. Given the current situation, few states are expected to expend the resources required to complete rigorous evaluations. This in fact was identified as a significant problem in a National Academy of Sciences (NAS) report on the effectiveness of I/M programs released in 2002. However, the impact of the NAS report was significantly diluted by its overemphasis on remote sensing for program evaluation purposes.

On October 5, 2006, EPA's Office of the Inspector General (IG) issued a report entitled, "EPA's Oversight of the Vehicle Inspection and Maintenance Program Needs Improvement."[37] In this investigation, the IG's office investigated I/M programs in Region 3 for compliance with their I/M program commitments. The report concludes that EPA has not ensured that states have fully met their I/M program commitments and that four of the five I/M programs in Region 3 reported substantial percentages of vehicles with no known final outcome. The report further concluded that from1999 to 2004, only 11 of the 34 I/M programs submitted required reports to EPA. The final conclusion from the report states that because of this lack of reporting and oversight, EPA does not have reasonable assurance that emission reductions claimed by some I/M programs have been achieved.

Unlike the U.S., the regulation of in-use vehicles in Canada does not fall under the federal authorities but under each provincial jurisdiction. Environment Canada (the equivalent of the U.S. EPA) offers some guidance on a code of practice for I/M programs, but it does not have any authority to regulate the programs. Both of Canada's provincial I/M programs (British Columbia and Ontario) resulted from regional concerns with the prevention of air quality degradation. Although Canada does have national air contaminant standards, it has no systematic methods (like the NAAQS, SIPs, or sanctions) to ensure that areas meet these standards.

6.2 Program Design Features

Table 18 presents information regarding 51 distinct I/M programs operating in North America. A key to the codes used to describe various program features appears at the end of the table. For example, the letter "D" under the column labeled "Network Type" means "decentralized" and "C" means "centralized." Under "Inspection Frequency," "B" means "biennial" and "A" means "annual." Many of the entries are self-explanatory.

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[37] See *http://www.epa.gov/oig/reports/2007/20061005-2007-P-00001.pdf*

Table 18
Design Features of Currently Operating Canadian and United States I/M Programs

State – Program Area	Program Required	Network Type	Inspection Frequency	Vehicles Included	Model Years Exempt	Model Years Included	Tailpipe Test included	OBD Pass/Fail	Evap Pressure Test/ Gas Cap Test	Repair Cost Ceiling	Safety Insptn.	Tight Standards	Enforcement Method	Contract End; Program Termination	Move to OBD Only planned
AK - Anchorage	B	D	B	G<12,000	6 Yrs	≥1968	TSI	Yes	No/No	$450	No	Yes	S/R	Under Review	No plan
AZ – Phoenix	E	C	A/B	G-All Weight Classes	5 Yrs	≥1967	IM147, I, SS	Yes	Yes/Yes	$200-$450	No	Yes	R	Contract 7/2014; Statutory 1/2017	No plan
				D-All Weight Classes	5 Yrs	≥1967	SI	N/A	-						
AZ – Tucson	B	C	A	G-All Weight Classes	5 Yrs	≥1967	SS, I	Yes	No/Yes	$50-$300	No	Yes	R	Contract 7/2014; Statutory 1/2017	No plan
				D-All Weight Classes	5 Yrs	≥1967	LO	N/A	-						
British Columbia, Canada – Fraser Valley and Vancouver	N/A	C	A/B	G<5000kg	7 Yrs	All	IM240, ASM2525, I	Yes	No/Yes	$300-No Limit[38]	No	Yes	R	Contract 12/31/11; Continuation under study	No
				D<5000kg	7 Yrs	All	D147	-	-						
CA – Basic I/M	B	D	B	G<10,000	6 Yrs	≥1976	TSI	Yes	Yes/Yes	$450	No	Yes	R	No termination date	No authority to do OBD only
CA – Enhanced I/M	E	DTO	B	G<10,000	6 Yrs	≥1976	TSI, ASM2	Yes	Yes/Yes	$450/ None[39]	No	Yes	R	No termination date	No authority to do OBD only
CO – Enhanced I/M Denver and Boulder area	E	C/D	A/B	G – All Weight Classes	4 Yrs	All	IM240, TSI	No	No/Yes	$75-$715	No	Yes	R	Contract 12/2010; No program termination date	No plans
				D– All Weight Classes	2/4 Yrs	All	3-MODE WOT	N/A	-	$75-$1500					

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[38] Repair Cost Limit in Canadian Dollars

[39] No repair cost limit for "gross polluters."

Table 18
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State – Program Area	Program Required	Network Type	Inspection Frequency	Vehicles Included	Model Years Exempt	Model Years Included	Tailpipe Test included	OBD Pass/Fail	Evap Pressure Test/ Gas Cap Test	Repair Cost Ceiling	Safety Insptn.	Tight Standards	Enforcement Method	Contract End; Program Termination	Move to OBD Only planned
CT – Statewide	E	D	B	G<10,000	4 Yrs	24 MY+	ASM2, TSI	Yes	No/Yes	$660	No	Yes	R	Contract 5/2011; No program termination date	No plans
				D<26,000	4 Yrs	24 MY+	SI, LO	Yes	-						
DE – Kent and New Castle Counties	LE	C	B	G<8,500	5 Yrs	≥1968 Cars ≥1970 Trucks	TSI	Yes	Yes/Yes 1975-1995	$75-$738	Yes	No	R	No Termination date	No Plan
				D<8,500	5 Yrs	≥1997	-	Yes	-	$760					
DE – Sussex County	B	C	B	G<8,500	5 Yrs	≥1968 Cars ≥1970 Trucks	I	No	No/No	$855	No	No	R	No Termination date	No Plan
District of Columbia	E	C	B	G – 10,000	4 Yrs	≥1968 Cars	IM240, I	Yes	Yes	$450	Yes	No	S/R	No termination date	No Plan
GA- Atlanta Area	E	DTO/DTR	A	G≤8,500	3 Yrs	24MY+	ASM2, TSI	Yes	No/Yes	$788	No	No	R	Contract 2013; No statutory end	Once all covered models are OBD equipped
ID – Ada County	N	D	A	G – All Weight Classes	1 Yrs	≥1965	TSI	Yes	No/No	$200	No	No	R		
				D – All Weight Classes	1 Yrs	≥1965	SI		-						
IL – Chicago, Surrounding 6 County Area, and St Louis	E/B	D/C	B	G – All Weight Classes	4 Yrs	1996+	I (HD)	Yes	No/Yes (Non OBD)	$450	No	Yes	R	Contract 4/2013; No statutory end	No plan

Table 18
Design Features of Currently Operating Canadian and United States I/M Programs

State – Program Area	Program Required	Network Type	Inspection Frequency	Vehicles Included	Model Years Exempt	Model Years Included	Tailpipe Test included	OBD Pass/Fail	Evap Pressure Test/ Gas Cap Test	Repair Cost Ceiling	Safety Insptn.	Tight Standards	Enforcement Method	Contract End; Program Termination	Move to OBD Only planned
IN – Chicago Il Suburbs	E/B	C	B	G<9,000	4 Yrs	≥1976	IM93, I	Yes	No/Yes	$450	No	Yes	R	No termination date	No exact plans
LA –5-Parish Baton Rouge Area	LE	D	A	G<10,000	2 Yrs	≥1980	-	Yes	No/Yes	No limit	Yes	-	S	No termination date	No plans
MA – Statewide	LE	D	A	G-96+ >8,500 OBD, 08+ >14,000 OBD	1YR	≥1996	-	Yes	No/No	$590-790	Yes	-	S	Contract 9/2013; No program termination date	OBD only for for LD
				D-97+ >8,500, 07+ >14,000	1YR	≥1997	-	Yes	-						
				D>10,000	1 YR	≥1984	O	N/A	-	-					
MD – Baltimore / D.C. Suburbs	E	C	B	G<26,000	2 Yrs	≥1977	I	Yes	No/Yes	$450	No	Yes	R	Contract 2014; No program termination date	No Plan
ME – Portland	LE	D	A	G<14,000	-	≥1974	-	Yes	No/Yes	No limit	Yes	-	S	No termination date	No Plan
				D<14,000	-	≥1974	-	Yes	-						
MO – City/County of St. Louis, St. Charles, Jefferson & Franklin Counties	B	C/D	B	G < 8,500	2 Yrs	1996+ (Gasoline) 1997+ (Diesel)	-	Yes	No/No	$450	Yes	No	S/R	No termination date	OBD-only now
NC –48-County Area	B	D	A	G<8,500	1 Reg Cycle	96+ Emissions	-	Yes	No/No	$200	Yes	No	R	No termination date	OBD only now

Table 18
Design Features of Currently Operating Canadian and United States I/M Programs

State – Program Area	Program Required	Network Type	Inspection Frequency	Vehicles Included	Model Years Exempt	Model Years Included	Tailpipe Test included	OBD Pass/Fail	Evap Pressure Test/ Gas Cap Test	Repair Cost Ceiling	Safety Insptn.	Tight Standards	Enforcement Method	Contract End; Program Termination	Move to OBD Only planned
NH – Statewide	OTR	D	A	G – <8500	-	20 MY+	-	Yes	No/No	No limit	Yes	No	S	Gordon-Darby 6/2010; No legislative end	Once ’96 and newer only covered
				D – All Weight Classes	-	20 MY+	SI	Yes	-						
NJ – Statewide	LE	D/C	B	G – All Weight Classes	4 Yrs	All	TSI, I	Yes	No/Yes	$450	Yes	No	S	Contract 5/2013; No program termination date	No plan
				D- All Weight Classes	4 Yrs	All	-	Yes FOR MY97+ ≤8,500 LBS	-						
NM – Albuquerque	B	D	A/B	G<10,001	2 Reg Cycle	≥1975	TSI	Yes	No/Yes	$300	No	No	SR	Required to test thru 2016 but no “sunset”	No plans
				D<10,001	2 Reg Cycle	≥1975	O	N/A	-						
NV – Clark and Washoe Counties	LE/B	D	A	G<All Weight Classes	2 Yrs	≥1968	TSI	Yes	No/No	$200-$450	No	No	R	No termination date	No plan
				D<14,001	2 Yrs	≥1968	LO	N/A	-						
NY –53 "Upstate" Counties	LE	D	A	G<8,500	2 Yrs	25 MY+	-	Yes	No/No	$450	Yes	-	S/R	Contract 12/2011; SIP request to end 12/2010	No plan
NY – New York Metropolitan Area	E	D	A	G -All Weight Classes	2 Yrs	25 MY+	NTTEST, I	Yes	No/Yes	$450	Yes	Yes	S/R	Contract 12/2011; SIP request to end 12/2010	No plan
				D>8,500	0 Yrs	HDD All	SI	N/A	-	$1,000-$4,000	Yes	No	S		

Table 18
Design Features of Currently Operating Canadian and United States I/M Programs

State – Program Area	Program Required	Network Type	Inspection Frequency	Vehicles Included	Model Years Exempt	Model Years Included	Tailpipe Test included	OBD Pass/Fail	Evap Pressure Test/ Gas Cap Test	Repair Cost Ceiling	Safety Insptn.	Tight Standards	Enforcement Method	Contract End; Program Termination	Move to OBD Only planned
NYC – Taxi and Limousine Commission	E	C	3X(A)	G<8,500	0 Yrs	1996+	-	Yes	No/No	-	Yes	-	S/R		Already OBD only for emissions
OH – Cleveland / Akron	E/B	C	B	G<10,000	4 Yrs	25 MY+	ASM2525, TSI	Yes	No/Yes	$200-$300	No	No	R		
				D<10,000	4 Yrs	25 MY+	LO	Yes	-						
Ontario, Canada	N/A	D	A/B	LDV=1988+ HDV=All	5 Yrs and Hybrids	LD≥1988	ASM 2525, I,O	N/A	No/Yes	$450[40]	No	Yes	R	6/2011; No statutory end	Proposed for 2012, ’98 and later models
						HD All	SI								
OR – Portland	B	C	B	G-All	4 Yrs	≥1975	I	Yes	No/No	No limit	No	Yes	R	No termination date	When tested models are OBD equipped
				D<8,500	4 Yrs	≥1975	I	Yes	-						
OR – Rogue Valley	B	C	B	G-All	4 Yrs	20 MY+	I	Yes	No/No	None	No	Yes	R	No termination date	When tested models are OBD equipped
				D<8,500	4 Yrs	20 MY+	I	Yes	-	No limit					
PA – Philadelphia	E	D	A	G<9,000	1 YR	1975+	ASM5015, TSI	Yes	No/Yes	$150	Yes	No	S		
PA – Pittsburgh	E	D	A	G<9,000	1 YR	1975+	I, TSI	Yes	No/Yes	$150	Yes	No	S		
PA – Remainder of State	N	D	A	G<9,000	1 YR	All	-	Yes	No/Yes	$150	Yes	No	S		

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[40] Repair Cost Limit in Canadian Dollars

Table 18
Design Features of Currently Operating Canadian and United States I/M Programs

State – Program Area	Program Required	Network Type	Inspection Frequency	Vehicles Included	Model Years Exempt	Model Years Included	Tailpipe Test included	OBD Pass/Fail	Evap Pressure Test/ Gas Cap Test	Repair Cost Ceiling	Safety Insptn.	Tight Standards	Enforcement Method	Contract End; Program Termination	Move to OBD Only planned
RI – Statewide	E	D	B	G<8,500	2 Yrs OR 24,000 MI	All	RI2000, TSI	Yes	No/Yes	$700	Yes	No	S/R		
				D<8,500	2 Yrs OR 24,000 MI	All	O	N/A	-	$700					
TN - Davison County	B	C	A	G<10,500	1 YR	≥1975	TSI	Yes	No/Yes	No limit	No	No	R	No termination	No plan
				D<10,500	1 YR	≥1975	O	N/A	-						
TN - Hamilton, Rutherford, Sumner, Williamson, and Wilson counties	B	C	A	G<10,500	1 YR	≥1975	TSI	Yes	No/Yes	$75-$650	No	No	R	No termination	No plan
				D<10,500	1 YR	≥1975	O	Yes	-						
TN - Memphis	B	C	A	G<26,000	-	All	I	N/A(Yes 5/10)	No/No	$75-$650	Yes	No	R	No termination	No plan
TX – Dallas-Ft. Worth Area	LE	D	A	G – All Weight Classes	2 Yrs	24 MY+	ASM2, TSI	Yes	No/Yes	at least $600	Yes	No	S/R	No Termination dates	No plan
TX – El Paso County	LE	D	A	G – All Weight Classes	2 Yrs	24 MY+	TSI	Yes	No/Yes	at least $600	Yes	No	S/R	No Termination dates	No plan
TX – Houston-Galveston-Brazoria Area	LE	D	A	G – All Weight Classes	2 Yrs	24 MY+	ASM2, TSI	Yes	No/Yes	at least $600	Yes	No	S/R	No Termination dates	No plan
TX – Travis & Williamson Counties	N/A	D	A	G – All Weight Classes	2 Yrs	24 MY+	TSI	Yes	No/Yes	at least $600	Yes	No	S/R	No Termination dates	No plan

Table 18
Design Features of Currently Operating Canadian and United States I/M Programs

State – Program Area	Program Required	Network Type	Inspection Frequency	Vehicles Included	Model Years Exempt	Model Years Included	Tailpipe Test included	OBD Pass/Fail	Evap Pressure Test/ Gas Cap Test	Repair Cost Ceiling	Safety Insptn.	Tight Standards	Enforcement Method	Contract End; Program Termination	Move to OBD Only planned
UT – Davis	B	D/C	A/B	G – All Weight Classes	12 MO	≥1968	TSI	Yes	No/No	$450	Yes	Yes	R		
				D – All Weight Classes	12 MO	≥1968	LO, SI	N/A	-	$750-$1500					
UT – Salt Lake	B	D	A/B	G – All Weight Classes	12 MO	≥1968	ASM2, TSI	Yes	No/Yes	$100-$450	Yes	Yes	R		
				D – All Weight Classes	12 MO	≥1968	LO, SI	N/A	-	$750-$1,500					
UT – Utah County	B	D	A/B	G – All Weight Classes	12 MO	≥1968	TSI	Yes	No/Yes	$100-$400	Yes	Yes	R		
				D – All Weight Classes	12 MO	≥1968	LO, SI	N/A	-	$750-$1500					
UT - Weber	B	D	A/B	G – All Weight Classes	12 MO	≥1968	TSI	Yes	No/No	$100-$400	Yes	Yes	R		
VA – Northern Counties and Five City Program Area	E	D	B	G<10,000	2 Yrs	24 MY+1997+	ASM2, TSI	Yes	No/Yes	$715	Yes	No	R	Contract 7/2012; No program termination date	No plan
				D<8,500											
VT- Statewide	OTR	D	A	G<8,500	-	All (cat and gas cap)	-	Yes (96+)	No/No	No limit	Yes	No	S	No termination date	OBD only except for visual check
				D<8,500	-	All	-	Yes (97+)	-						

Table 18
Design Features of Currently Operating Canadian and United States I/M Programs

State – Program Area	Program Required	Network Type	Inspection Frequency	Vehicles Included	Model Years Exempt	Model Years Included	Tailpipe Test included	OBD Pass/Fail	Evap Pressure Test/ Gas Cap Test	Repair Cost Ceiling	Safety Insptn.	Tight Standards	Enforcement Method	Contract End; Program Termination	Move to OBD Only planned
WA – Puget Sound / Spokane / Vancouver	LE/B	C	B	G – All Weight Classes	4 Yrs	24 MY+	ASM2525, TSI	Yes	No/Yes	$150	No	No	R	Contract 6/2012; Program termination 7/2019	No plan
				D – All Weight Classes	4 Yrs	24 MY+	ASM2525, SI	N/A	-						
WI – Enhanced Program	E/B	C	C	My 96-06; G≤8,500 MY 07 & Newer; G&D≤14,000	3 Yrs	1996+	None	Yes	No/No	$200-787[41]	No	No	R	Contract ends 6/2011; No termination date	Already OBD only

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[41] $450 indexed to CPI per EPA guidelines. Wisconsin DNR is in process of modifying its I/M rule so that ceiling applies in Sheyboygan County. The only county with $200 limit.

Table 18 (continued)
Design Features of Currently Operating I/M Programs, Key to Symbols

Program Required	N/A B E LE OTR E/B	Not Applicable Basic Enhanced Low-Enhanced Ozone Transport Region Enhanced and Basic Elements
Type	C D DTO C/D	Centralized Decentralized Decentralized with Test Only Stations Required for Certain Vehicles Centralized and Decentralized Elements
Inspection Frequency	A B A/B	Annual Biennial Annual and Biennial Elements
Vehicles Included	G D	Gasoline Vehicles Diesel Vehicles
Model Years or Mileage Exempt	(x) Yrs (xx) Mo (x) reg cycle (xx,xxx) Mi	New vehicles are exempt for (x) years. New vehicles are exempt for (xx) months New vehicles are exempt for (x) registration cycles New vehicles are exempt for (xx,xxx) miles
Model Years Included	∃19xx xx MY+ All	19xx and newer model years (some newer models may also be exempted) The xx most recent model years All model year vehicles are tested
Tailpipe Test Type	I TSI SSI IM240 IM147 BAR31 RI2000 ASM5015 ASM2525 ASM2 SS O LO SI 3 Mode	Curb Idle Two Speed Idle (2500 rpm while engine is unloaded and curb idle) Single Speed Idle 240 Second Transient Test 147 Second Transient Test 31 Second Transient Test Similar to BAR31 Transient Test Acceleration Simulation Mode 5015 Acceleration Simulation Mode 2525 Both ASM2525 and ASM5015 Modes Steady State Loaded Test Opacity Loaded Opacity Test Snap Idle Opacity Test Three Mode Wide-Open Opacity Test

OBD Pass/Fail	Yes No -	Failed OBD Inspection Results in Overall Inspection Failure Failing OBD Results in Advisory Notice or Defaults to Tailpipe Inspection No OBD Test is Performed
Evaporative Pressure Test/ Gas Cap Test	No/No Yes/No No/Yes Yes/Yes	No Evaporative Pressure or Gas Cap Test Evaporative Pressure Test, No Gas Cap Test Gas Cap Test, No Evaporative Pressure Test Both Gas Cap and Evaporative Pressure Test
Repair Cost Limit	$xxxx	Repair Cost Limit in U.S. Dollars
Safety Inspection	Yes No	Program Requires Safety Inspection Program Does Not Require Safety Inspection
Enforcement Method	R S S/R	Denial of vehicle registration. Windshield Sticker Combination registration denial and windshield sticker
Tight Standards?	Yes No -	Exhaust standards are stringent Exhaust standards are lenient Emissions are not measured in program.

Under the column heading "Tight Standards," "Yes" means that exhaust emissions standards are set at a level that is expected to identify defective vehicles without a significant percentage of false failures. "No" means the standards are set at a level that is unnecessarily lax.

As shown in the table, only 31% of the programs require testing in a centralized network. A few programs have a combination of centralized and decentralized testing and the majority of the programs use decentralized inspection stations. All of the programs using decentralized testing are believed to have significant problems with inspection quality and fraudulent testing. This conclusion is based on enormous amounts of data collected from the California program using (1) the results of inspections of vehicles with obvious defects taken to inspection stations by state employees posing as ordinary motorists, and (2) the comparison of inspection results for vehicles detained at roadblocks set up by the California Highway Patrol with inspection results for the same vehicles when tested at decentralized stations. (This problem has persisted for more than 20 years despite extraordinary efforts by the State of California to monitor station performance and take enforcement action.)

Another indication that many of the U.S. programs are less effective than they could be is that about one-third of the programs have repair cost limits that are significantly lower than the $779 we calculate to be required under the plain language of the Clean Air Act. Four of the states exclude pre-1996 model year vehicles even though they represent a significant fraction of vehicle emissions. Seven of the states do not have program compliance as a prerequisite for registration renewal.

To provide an overall sense of how the various I/M programs compare to one another, Sierra assigns a grade, ranging from A to F, to each program. For most programs, the rating is based on our evaluation of program features rather than on data analysis.

The first factor we consider in evaluating the overall performance of an I/M program is whether inspections are conducted at centralized, special purpose facilities under the control of a single entity or in decentralized, independent automotive repair shops. (There is overwhelming evidence available from multiple investigations conducted in California that inspections are more likely to improperly performed or falsified in decentralized facilities.) Other important factors include stringency of standards, inspection fees, and repair cost limits. Our rating reflects the number and significance of program design features that detract from the program's emission reduction effectiveness. Thoroughness of the underhood inspection and the exhaust emissions test is also evaluated, with idle-only I/M programs being rated as less effective than those employing loaded-mode tests. Our grading criteria also account for the growing population of OBDII-equipped vehicles and increasing significance of OBDII testing. The OBD-related criteria include compliance to EPA readiness monitor guidelines and treatment of "not-ready" vehicles.

It should be noted that our grading method does <u>not</u> address the enforcement of program requirements, other than inspection prior to registration renewal, nor does it address possible regional differences in repair quality. (We do not believe regional differences in repair quality to be significant, but there are major regional differences in enforcement of program requirements.)

Considering all of the features of each program, we give 21 of the programs a grade of "F," indicating that they are unlikely to provide any significant reduction in emissions. At the other end of the spectrum, we give a grade of "A-" to the program in Phoenix, Arizona. In its current form, we would give the AirCare program a B+. (The proposed enhancements would bring the grade to an A.)

6.3 Program Trends

OBD-Only Testing – The last column of Table 18 is labeled "Move to OBD-Only Planned." This column identifies the most significant trend in I/M programs. By allowing equivalent credits for OBD-only inspections, EPA has encouraged a number of states to drop tailpipe testing for 1996 and newer vehicles. Massachusetts, Missouri, North Carolina, Vermont, and Wisconsin are doing OBD-only testing now. Georgia, New Hampshire, and Oregon are planning to switch to OBD-only testing in the future. On January 28, 2010, a switch to OBD-only testing for 1998 and newer models was also proposed for the Ontario I/M program.

There are several states experimenting with remote monitoring of OBD systems and self-service OBD kiosks, but, as discussed in more detail below, there is no real "trend" in this area.

Enhanced Evaporative Emissions Testing – A Low-Pressure Fuel Evaporative Test (LPFET) was added to the California I/M program in December 2007. The purpose of the test is to improve the detection of evaporative emissions control system defects in vehicles that are not equipped with OBD systems. As shown in Table 18, only two other states (Arizona and Delaware) and the District of Columbia employ a similar pressure testing procedure.

California is also requiring a visual inspection for liquid leaks, but visual inspections are notoriously ineffective, especially in decentralized programs. Automated liquid leak testing procedures have also been investigated. ESP and the Indiana Department of Environmental Management have developed a leak detection procedure using handheld HC sniffers. The pilot program reportedly detected liquid leaks in a significant percentage of vehicles with high HC emissions measured during CVS testing.

Decentralized Testing – A decentralized testing option has been added to the Illinois program.

Remote Sensing – Since their I/M programs were originally established, several states have incorporated some sort of testing with remote sensing devices (RSDs). Although not shown in Table 18, 13 states use some form of remote sensing. At one end of the spectrum, California and Arizona use periodic remote sensing primarily for research and fleet characterization purposes. At the other end of the spectrum, Colorado and Virginia report using a “clean screen” element in their program (exempting vehicles from I/M testing that are measured as having low emissions via remote sensing). Virginia also calls vehicles in for earlier testing if they are measured to be high emitters.

Program Evaluation and Enforcement – Although it’s not apparent in Table 18, less focus on program evaluation and enforcement is another trend affecting many U.S. programs. This trend is associated with the previously mentioned lack of enforcement and oversight by EPA. Although EPA regional offices are theoretically responsible for monitoring states’ compliance with I/M requirements, the regional offices lack the expertise necessary and the effectiveness of most U.S. I/M programs is suffering as a result.

Program Termination – A less significant trend is the termination of I/M programs. The most recently terminated program was Fairbanks, Alaska, which ended effective January 1, 2010. Termination of the Anchorage, Alaska program is also a possibility; however, both the Fairbanks and Anchorage programs were focused on carbon monoxide and air quality levels have improved significantly since the programs were implemented in the 1980s. Other programs that have been cancelled during the last ten years include Florida, Oklahoma, Kentucky, and portions of Colorado, Ohio, and Indiana. This trend may soon be reversed as a result of EPA’s proposed tightening of the ambient air quality standard for ozone, which will result in more areas being designated “nonattainment.”

6.4 Alternative Test Issues

OBD-Only Testing – OBD-only testing of aging vehicles as a potential problem for the future. The specific concern is that older OBDII-compliant vehicles with deteriorating emission control system performance (due to mileage and age) are likely to experience a high rate of OBD trouble codes even though emission levels remain close to zero. This is possible because of the stringency of the MIL illumination criteria that have been imposed. As a result, the repairs required to extinguish a MIL can have relatively little emissions benefit. In fact, there may be no benefit in some cases (i.e., when a sensor fails that is part of the OBDII system but does not actually affect emissions from the vehicle). The cost-effectiveness of such repairs would be very poor and, for older vehicles, the repair cost could exceed the vehicle’s resale value. To the extent that aftermarket catalysts are used to reduce the cost associated with repairs prompted by a DTC related to catalyst efficiency, the long-term effect of repairs could actually be an increase in emissions.

While the magnitude of the above-described problem with aging OBD vehicles is not yet clear, it will certainly be an issue that needs to be addressed during any post-2011 AirCare program. If the program continues, test procedures should be designed so that tailpipe testing can automatically be used in lieu of OBD-only testing for certain combinations of DTCs and vehicle age/mileage accumulation. Sierra’s 2005 Phase 2 report suggested the use of tailpipe testing during the retest of OBD failures for older vehicles as one possible approach to minimize repair costs. Depending on the severity of the problem, that may not be an adequate response. Tailpipe testing during the initial inspection may be more appropriate, at least for the catalyst efficiency monitor.

<u>Alternative OBD Tests</u> – During the last Phase 1 review of the AirCare program in 2004, Levelton highlighted several alternative OBD test procedures that were under study, including self-service, OBD kiosks and wireless OBD systems. Sierra's Phase 2 study concluded that neither of the alternative OBD testing approaches were feasible for the next generation of the program. As discussed in more detail below, these alternatives have still not progressed to the point where they should be considered for incorporation into the post-2011 program.

Remote OBD Monitoring (OBDIII) – This concept involves monitoring OBDII-compliant vehicles on a continuous basis during in-use operation. It requires wireless electronic transmission of vehicle OBD system status to a central database. The basic feasibility of the concept was demonstrated over ten years ago.[42] Although not implemented on a full-scale basis in any inspection program to date, there have been several pilot tests, the most extensive of which is underway in California. The pilot tests typically involve the use of systems, such as those available from Networkcar,[43] that are already commercially available for fleet managers. In such applications, significant hardware and monitoring costs can be justified because the information being made available to the fleet manager goes far beyond the monitoring of OBD system status, such as instantaneous information on vehicle location. However, one time hardware costs of $395 per vehicle (<u>not</u> including installation) plus $25 per month for wireless network charges are far beyond what could be justified to save the cost of a biennial inspection and a centralized station. The ultimate feasibility of this technology depends on the extent to which economies of scale can be realized.

While the OBDIII concept could potentially eliminate the need for any stationary test capacity (e.g., at centralized inspection centres), this test method could also be implemented as a "motorist-choice" option in which vehicle owners are allowed to choose whether to enroll in the remote monitoring program or bring their vehicles in for periodic testing at an inspection centre. Under that approach, some level of stationary inspection capacity would need to be maintained to handle those vehicles whose owners choose to come in for periodic testing. Sufficient inspection capacity would also need to be provided for non-OBD vehicles subject to tailpipe testing.

Because OBDIII involves continuous monitoring of vehicle performance rather than just during the periodic scheduled inspections, it could yield additional emissions benefits associated with timely repair of emissions-related defects that might otherwise remain uncorrected until the next scheduled inspection. Remote OBD monitoring technology could also make it more difficult for individual motorists to evade I/M program

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[42] "Incorporation of Wireless Communications into Vehicle On-Board Diagnostic (OBD) Systems," Sierra Research Report No. SR00-01-03, prepared for California Air Resources Board, January 2000.

[43] http://www.networkcar.com

requirements. However, several practical issues, outlined below, adversely impact the current feasibility of OBDIII for other than fleet vehicles.

- New vehicles are not factory-equipped with remote monitoring systems that could be used for this concept and there are no current plans to require such systems on new vehicles, so the installation of aftermarket transponders would be required.

- When installed on a retrofit basis, the current costs for hardware, installation, and wireless network charges substantially exceed the cost associated with biennial inspections at centralized stations.

- At best, remote monitoring could be deployed only on 1998 and newer model year vehicles in British Columbia, meaning that it would not be capable of testing a large fraction of the current in-use fleet.

- Expanding from pilot-scale to full-scale testing is likely to raise a number of technical and practical issues that have not been identified and addressed in the testing performed to date. Significant concerns have been raised by privacy advocates over possible government intrusion issues related to this inspection option, mainly centering around the ability of the system to monitor where and how a vehicle is being operated at any given time.

Given the above issues, particularly the reliance on relatively new technology that has not been subject to full-scale implementation anywhere else, this is not considered a viable option for the next generation of the AirCare program.

Self-Serve OBD Kiosks – There have been several demonstrations of "self-service" OBDII kiosks in recent years. States in which demonstration programs have been conducted include Oregon, Washington, Illinois, New Hampshire, and California. During the previous Phase 2 evaluation, we provided detailed information on the kiosk systems developed by Gordon-Darby. Since then, additional companies that have developed systems include Applus+, SysTech, and ESP.

In concept, self-service OBD kiosks could be set up almost anywhere, including at gasoline stations and mini-marts. If this were a program option, one or more private businesses could be licensed to establish a network of such self-service testing kiosks. Alternatively, or in addition, kiosks could be installed at existing AirCare test stations.

Technological feasibility isn't really an issue. Kiosks are an option that could reduce the cost of initial inspections for 1998 and later model vehicles subject to OBD-only testing. However, there are several disadvantages to this testing approach that need to be considered:

1. Installation of OBD kiosks at existing AirCare stations is impractical because the time required for individual vehicle owners test their own vehicles would be

excessive and would create congestion problems in the lanes. Many, if not most, motorists will require assistance to use the kiosk because of the difficulty associated with finding the DLC and plugging a connector into it.

2. Installation of OBD kiosks at other locations will reduce the volume at the existing AirCare stations to the point where a convenient network of stations within a reasonable driving distance for most vehicle owners is no longer economically feasible. This would require moving inspections for older vehicles or vehicles needing some sort of waiver or alternative testing procedure to a new decentralized inspection network. To the extent that inspections are conducted in a decentralized network, the level of emissions reductions that can be expected from the program will be reduced.

3. The many motorists incapable of successfully complete the inspection process at a self-service location will need to find kiosk locations where an attendant is available. The total time required to complete the testing process at attendant-supported kiosk locations may be longer than the time required to obtain testing at the current AirCare network.

4. Because OBD-only testing is not optimum in certain situations (e.g., older vehicles with DTCs for catalyst efficiency) or with pre-1998 model vehicles, alternative testing locations are required. This complicates the program and potentially leads to motorist confusion and frustration. The appearance of fundamental differences on how vehicles of different ages are treated will also create concerns regarding equity.

Given the unknowns associated with making OBD kiosks a primary program option for 1998 and later models, the potential economic advantages are uncertain. In contrast, an adverse effect on emission reductions from the program is virtually certain. However, the use of OBD kiosks may be a reasonable option for certain fleet vehicles.

Mobile OBD Testing – In the Phase 2 report prepared for the last program evaluation, it was suggested that mobile OBD testing might be appropriate for fleet vehicles. Given the experience with OBD kiosk demonstrations, we consider that approach more promising.

<u>Evaporative System Testing</u> – The California LPFET test is used to leak test 1995 and older (pre-OBDII) vehicles by monitoring the rate of pressure decay after pressurizing the system. A clamp is used to pinch the vapor line from the fuel tank to the canister and pressure is applied to the tank through the fuel inlet. Vehicles that cannot be tested without vehicle disassembly may be waived from testing. CARB staff reported it was able to perform the pressure test on 92% of 1500 vehicles tested during development of the procedure.

After one year of in-the-field experience, the fraction of vehicles for which pressure test results are reported remain significantly below that benchmark. Table 19 displays the results for vehicles tested by model year. The "Not Applicable" category is used when a technician feels that it is not possible to perform the test without damage or disassembly of the vehicle.

Table 19
LPFET Results by Model Year

MY	Fail	Not Applicable	Pass	Total Tested	% Tested
1975		5	3	8	38%
1976	70	615	396	1,081	43%
1977	144	810	573	1,527	47%
1978	144	844	757	1,745	52%
1979	220	890	865	1,975	55%
1980	107	568	657	1,332	57%
1981	70	570	714	1,354	58%
1982	99	589	981	1,669	65%
1983	95	687	1,292	2,074	67%
1984	203	1,181	2,704	4,088	71%
1985	257	1,325	3,954	5,536	76%
1986	372	2,025	5,542	7,939	74%
1987	450	2,479	7,410	10,339	76%
1988	473	2,083	8,502	11,058	81%
1989	691	2,705	11,926	15,322	82%
1990	710	3,186	14,580	18,476	83%
1991	749	3,528	17,585	21,862	84%
1992	705	3,386	16,611	20,702	84%
1993	895	4,330	20,307	25,532	83%
1994	1,356	6,337	23,604	31,297	80%
1995	1,040	10,485	24,301	35,826	71%
ALL	8,850	48,628	163,264	220,742	78%

Note that as the total number of vehicles from a particular model year drops, the percentage of vehicles receiving the pressure test drops proportionately. Fewer than 60% of the 1981 and older vehicles were tested. The design of these older vehicles makes it easier to access the canister and vent lines, but the variety of designs and the limited number of vehicles seen by an individual technician may make it difficult to efficiently identify and properly test such vehicles. This is a critical problem as the oldest vehicles are the ones most likely to fail. About 5% of the 1995 and older model year vehicles are failing the recently implemented LPFET test.

One concern with the application of pressure testing in a centralized program is that a certain number of vehicles *will* have evaporative hoses damaged during the course of testing. This is less of a concern in a decentralized program at which the inspection is being performed at a facility that is capable of repairing such problems.

Decentralized Testing – From 2005 through early 2009, Sierra was under contract to the California Air Resources Board to evaluate the effectiveness of the state's decentralized I/M program (called Smog Check). Sierra analyzed data collected both at Smog Check stations and from vehicles randomly selected for roadside testing at road blocks set up by the California Highway Patrol. Despite the enormous effort being made by hundreds of employees at the California Bureau of Automotive Repair involved in enforcement, the analysis indicated that improper testing and/or fraud continues to be a problem with decentralized inspections.[44] Based on data collected between February 2003 and April 2006, the percent of pre-1996 vehicles failing a roadside emissions test within one year of passing a re-test at a decentralized inspection station was 59%. Analysis of the roadside failure rate as a function of time since passing the decentralized test indicated that post-I/M deterioration was not significantly contributing to the problem. In other words, the analysis indicated that most of the vehicles failing at the roadside were never actually repaired.

Figure 25 illustrates the trend observed. Roadside test results were segregated into four time bins: (1) 0-6 months following a decentralized inspection; (2) 6-12 months following inspection; (3) 12-18 months following inspection; and (4) 18-27 months following inspection. The last time bin was extended beyond two years to allow additional time for motorists that might delay the completion of their biennial inspection cycle.

The results are presented in Figure 25 separately for vehicles that were initial test failures and initial test passes during their previous Smog Check cycle. (Results presented are for tailpipe inspections only, irrespective of visual or functional failures.) The straight lines fit through the averages of the binned data cross the y-axis ("0" days after Smog Check) at a relatively high failure rate of 17% for vehicles that passed their initial Smog Check and 45% for vehicles that initially failed. This indicates that there appears to be a high failure rate at the roadside immediately following a passing Smog Check inspection for both initially passing vehicles and initially failing vehicles. If all of the vehicles actually passed their last test at a Smog Check station, it would be expected that the lines should go through the origin (i.e., zero failures at time = 0 following certification), but they do not.

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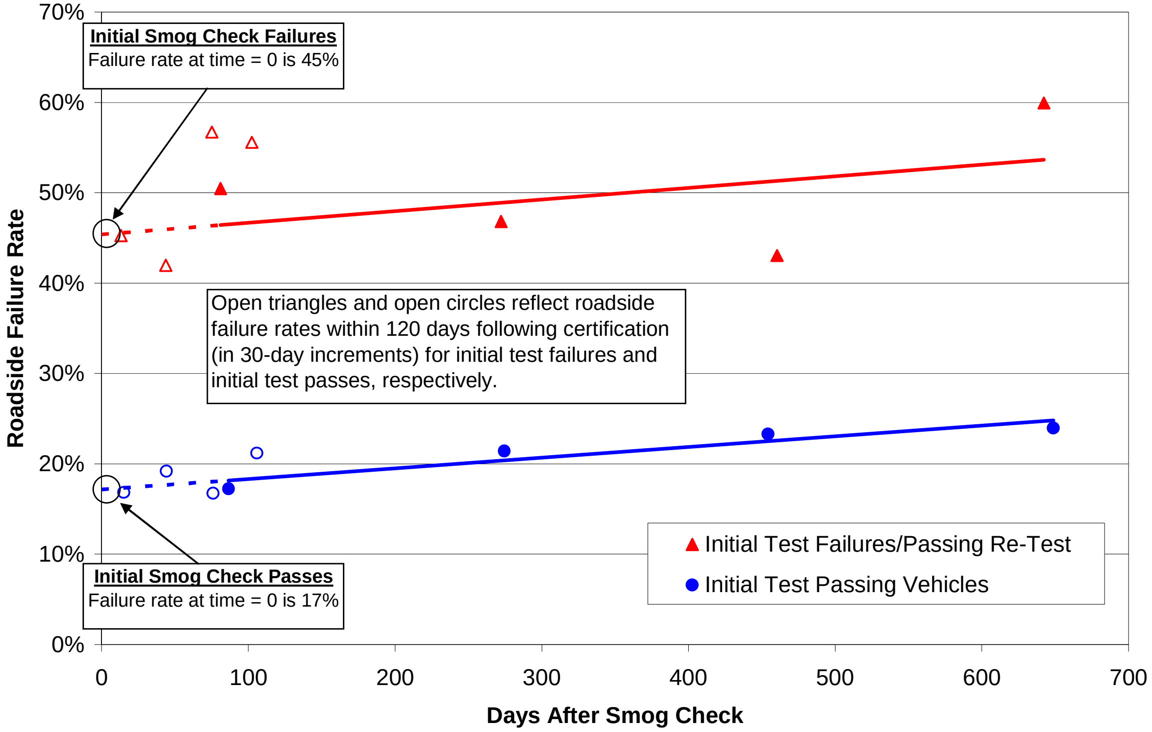
[44] T.C. Austin, et al., "Evaluation of the California Smog Check Program Using Random Roadside Data," Sierra Research Report No. SR09-03-01, March 12, 2009.

Figure 25
Roadside Tailpipe ASM Failure Rates for 1976-1995 Model Year Vehicles for Initial Smog Check Test Passing and Failing Vehicles Certified at Time = 0



The "hollow" data points shown on Figure 25 represent subsets of data from the 0-6 month bin. Each hollow point represents data from four 30-day periods following the official Smog Check inspection: 0-30 days, 31-60 days, 61-90 days, and 91-120 days. The fact that these data points fall along the same lines provides additional evidence that most vehicles observed to be failing at the roadside were failing immediately after having been reported as passing at a decentralized station.

Further data analysis found that the high failure rates following the Smog Check inspection do not appear to be explained by owner tampering following a passing test. Considering all of the vehicles tested at the roadside test, the tampering rate for vehicles that initially failed during their previous Smog Check cycle was only 9%, which was not significantly different from the 8% tampering rate for vehicles that initially passed their Smog Check.

An analysis was also conducted to determine whether the higher roadside failure rates observed for vehicles that initially failed their last Smog Check might have been due to test-to-test variability. Vehicles that were marginally passing the test would be more likely to fail a subsequent test due to test-to-test variability. However, the average passing test results for vehicles that initially failed were almost identical to the average test results for vehicles that initially passed. In fact, on average, the HC and NOx emissions for both groups of vehicles were only 45% of the emissions standards. CO emissions were even lower.

Previous studies have also produced evidence that a significant fraction of vehicles with emissions-related defects are not properly repaired under California's decentralized program. During an analysis conducted in 2003, test results from random samples of vehicles tested at the roadside indicated single-cycle exhaust emission benefits (ignoring the residual benefits of previous inspection cycles) of 16% for HC, 14% for CO, and 10% for NOx for vehicles subject to ASM testing.[45] These results can be compared to the single-cycle reductions achieved during a special study in which a random sample of vehicles were accurately tested and repaired under the supervision of state officials. The special study indicated single cycle reductions of 34% for HC, 35% for CO and 22% NOx for 1980 and later models.[46] By comparing the two studies, it appears that the California program was about 50% as effective as an "ideal" program circa 2000.

As more of the fleet subject to I/M receives OBD testing, the overall effectiveness of decentralized testing relative to centralized testing is expected to improve, at least in California where significant resources are dedicated to enforcement. However, a detailed evaluation of decentralized program effectiveness for OBD-equipped vehicles has not yet been conducted.

An advantage of decentralized testing is the additional convenience to vehicle owners associated with being able to choose from many more testing locations. When the testing is done at a facility also in the automotive repair business, repairs to failing vehicles can often be made where the initial test is performed, eliminating "ping-ponging" between test and repair facilities, and saving additional time for these vehicles. Waiting time for tests can also be very short if an appointment is made. Conversely, the test time will be somewhat longer and waiting times can also be longer if an appointment is not made. Limiting the network to a smaller number of repair garages (as in the Connecticut program) in order to better control quality and cost would reduce the improvement in convenience to the extent that it limits motorists' test choices.

In addition to effectiveness problems, decentralized testing is more expensive than centralized testing if dynamometer testing is required. Because of the inherently lower throughput associated with a decentralized inspection station, the capital cost of the equipment required has to be amortized over a small number of tests. Based on detailed cost comparisons performed for the California program, decentralized ASM testing would be roughly twice as costly as a centralized ASM program, while decentralized IM240 testing would cost almost three times as much as a centralized IM240 program.

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[45] "California Enhanced I/M Program Evaluation, Technical Support Document, Part 2 available at: http://www.arb.ca.gov/msprog/smogcheck/jun04/tsd_part2.pdf

[46] T.C. Austin and P.L. Heirigs, "The Effectiveness of IM240 Testing, ASM Testing, and Remote Sensing Based on the California I/M Pilot Project," Sierra Research, Inc. presentation at the 16th North American Motor Vehicle Emissions Control Conference, March 1995.

Remote Sensing – As noted above, RSD technology is used in several areas for a variety of purposes ranging from program evaluation to supplementing an annual or biennial I/M test. Although the accuracy and representativeness of RSD test results have improved significantly over time, a number of issues remain, including the following:

- High fractions of false failures and/or false passes due to the limitations of a "snap shot" sample that cannot represent the range of typical operating conditions as well as a transient dynamometer test;
- Poor fleet coverage rates due to the limited number of locations where testing is feasible; and
- Significant ambient limitations. RSD does not work well during non-daylight hours or under inclement (e.g., rainy) conditions.

Most of these limitations have been identified in past assessments of RSD feasibility.[47] The inconsistency in the mode being measured by a remote sensing device contributes to extremely poor correlation between remote sensing measurements and measurements of the same vehicles testing on a prescribed test procedure, like the IM240. Although remote sensing technology is improving over time, it is not keeping up with changes in the vehicle fleet. The problem with false passes is increasing for vehicles certified to meet Tier 1 and Tier 2 standards which have near zero emissions when warmed up. Defects related to emissions during cold start and warmup are more significant and not amenable to detection via RSDs. Since the last program review, the problem related to fleet coverage has also been better defined.

Subsequent to the previous program review, Sierra completed the most comprehensive evaluation ever performed of the potential for using remote sensing to identify vehicles with emissions related defects in a typical metropolitan area.[48] Based on a detailed survey conducted in the Sacramento, California metropolitan area, only about 20% of passenger cars and light-duty trucks registered in the area use freeway ramps that have operating conditions suitable for the measurement of exhaust emissions by remote sensing devices most of the time. Most vehicles use ramps that are either physically unsuitable for remote sensing (e.g., multiple lanes) or that usually have operating conditions (e.g., high congestion levels) that are unsuitable for remote sensing due to inadequate separation between passing vehicles or vehicle operating conditions that are poorly correlated with average emissions in stop-and-go driving.

An estimated 50% of the fleet can eventually be measured on freeway ramps under suitable operating conditions if monitoring is done for an extended period of time (i.e.,

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[47] "Analysis of the Effectiveness and Cost-Effectiveness of Remote Sensing Devices," prepared for U.S. Environmental Protection Agency, by Sierra Research, Inc., Report No. SR94-05-05, May 18, 1994.

[48] T.C. Austin, et al., "Fleet Coverage Limitations and Cost of Remote Sensing Devices for the Measurement of Motor Vehicle Emissions," Sierra Research Report No. 2005-11-02, November 29, 2005.

many weeks) at all ramps that are physically suitable. This estimate is based on the fact that there is a finite, non-zero probability of measuring a vehicle under suitable operating conditions even at ramps that routinely have unsuitable vehicle operating conditions. The other half of the fleet either does not frequently use the freeway system or uses ramps that are physically incompatible with the use of remote sensing.

Given the practical problems associated with making emissions measurements on surface streets, the potential for measuring vehicle emissions with remote sensing devices is more limited than has been previously realized. This conclusion is due in part to the fact that the vehicle operating range over which remote sensing measurements correlate with average emissions in stop-and-go driving is narrower than others have assumed. A more significant factor affecting our conclusions is that the study area, like most other metropolitan areas in California, has more extensive use of multilane on-ramps with ramp metering. Such ramps are not suitable for remote sensing for two reasons. First, two separate lanes of traffic make it impractical to identify individual vehicle exhaust plumes. Second, ramp meters routinely produce vehicle operating conditions (deceleration and queues approaching the meter and hard acceleration after the meter) that are outside the range of operation that correlates with average emissions in stop-and-go driving.[49]

The survey, which was conducted using an instrumented vehicle, found the following:

- 48% of the ramps surveyed (225 of 471) were determined to be unsuitable for remote sensing in any time period, due to multiple lanes, speed consistently outside the target range, engine load consistently outside the target range (usually due to excessive acceleration, deceleration or grade), inadequate space to position equipment, inadequate vehicle spacing, problems associated with active ramp metering, or for other reasons. One hundred (100) of the unsuitable ramps (21% of all 471 ramps) were physically unsuitable, usually because they had multiple lanes.

- 52% of the ramps surveyed (245 of 471) were determined to be suitable during at least one time period of the day. During the AM-, PM- and off-peak travel periods, respectively, 40%, 37% and 33% of the ramps were suitable for remote sensing, meaning that all suitability criteria were met for most vehicles in the respective time periods.

- 22% of the ramps (103 of 471) were found “suitable” for most vehicles in all three travel periods but only 5% of the ramps (24 of 471) were found to be “good” or “very good” ramps, meaning that almost all light-duty vehicles (rather than just “most” light-duty vehicles) would normally be expected to operate over a suitable range of speed and load in a consistent, predictable location along the ramp.

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[49] However, it should be noted that some dual lane sites may be acceptable for RSD measurements if the use of data collected is limited to applications that do not require individual measurements that are in the representative range of operating conditions. For example, such sites could be used to identify vehicles that are not locally registered.

Merging of the instrumented vehicle survey results with trip information derived from a regional traffic model showed that a typical deployment of remote sensing equipment, rotated between the sites identified as suitable, would result in approximately 20% of the light-duty vehicle fleet receiving a representative measurement by a remote sensing device in a relatively short period of time. Because ramps considered unsuitable would occasionally produce representative vehicle operating conditions, representative measurements could be obtained for a higher fraction of the fleet if remote sensing equipment were deployed at additional ramps. The longer the deployment, the greater the number of vehicles that could eventually be measured under representative conditions. However, because many of the ramps were physically unsuitable (regardless of congestion levels), and because a significant fraction of the fleet does not routinely use the freeway system, the upper limit for fleet coverage on freeway ramps is only about 50%.[50]

The inability of remote sensing devices to collect representative emissions measurements for the majority of the vehicle fleet limits the extent to which remote sensing can be used to either replace or augment a conventional vehicle I/M program. This limitation does <u>not</u> affect the ability to use remote sensing for emissions inventory or I/M program evaluation purposes, as long as any sample bias resulting from the feasible measurement sites is addressed. However, the use of remote sensing for these other purposes requires greater consideration of the distribution of vehicle operating conditions during which measurements are made. Previous efforts to use remote sensing for I/M program evaluation or emissions inventory purposes have not adequately addressed the extent to which results are affected by variations in vehicle operating conditions at the time of the measurement. Our analysis shows that much more sophisticated speed measurement systems are needed to improve the correlation between remote sensing measurements and average emissions in customer service.

In order to provide insight into the practicality of applying remote sensing to a typical metropolitan area having a population on the order of one million people, three scenarios were constructed and analyzed as to resource requirements and cost. The first scenario ("A") was designed to provide maximum fleet coverage, as would be needed if remote sensing were intended to effectively identify high emitting vehicles for repair. This scenario requires use of the greatest number of ramps and remote sensing units (some mobile and some fixed). The next two scenarios were intended to provide measurements of average exhaust emissions (grams per mile) from a statistical sample of the motor

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[50] Our estimate may be conservative in that it assumes that one-third of light-duty vehicles seldom, if ever, use the freeway system. This assumption was based on an instrumented vehicle study in which only two-thirds of light-duty vehicles used the freeway during the average one-week period of time that they were monitored. Some of the vehicles that do not use the freeway in a particular week would undoubtedly use the freeway eventually and, if remote sensing devices were deployed for a long enough period of time at enough ramps, would have their emissions measured. However, we have also made the assumption that valid measurements can eventually be obtained from vehicles using ramps with typically unsuitable vehicle operating conditions (e.g., predominantly decelerations). This assumption may be too optimistic.

vehicle fleet, grouped by model year, vehicle type, etc. Scenario B-1 considers the approach of using only manned, mobile remote sensing units, while Scenario B-2 considers the alternative of operating remote sensing only at unmanned, permanent sites. For the latter two scenarios, monitoring requirements (number of sites needed) depend upon the suitability of monitoring sites, amount of time spent at each site and other factors.

For maximum (i.e., about 50%) fleet coverage (with vehicles in a representative operating mode), 246 mobile sites and 126 permanent sites would be required with 27 remote sensing setups in all, at an annual cost (including annualized capital cost) of about US$8 million. This does not include the cost of confirmatory testing and repair of high emission vehicles, which is assumed to be borne by vehicle owners. Total cost borne by vehicles owners is estimated at US$5 million. (It also excludes any extraordinary legal costs associated with registration denial based on RSD measurements.)

The high cost to achieve maximum fleet coverage results largely from the extensive number of ramps at which monitoring would be required and the substantial staffing and labor costs that result. Assuming 5% of the vehicle fleet consists of grossly polluting vehicles that could be detected by remote sensing each year, the per-vehicle cost of identifying such vehicles in the study area was estimated to be US$400. This does not include the cost associated with confirmatory testing of vehicles called in based on remote sensing test results, nor does it include the cost associated with time spent by motorists. It also ignores the fact that the implementation of a call-in program based on remote sensing tests could induce motorists to take action that would reduce the cost-effectiveness (e.g., deliberately obscure license plates and avoid freeway ramps with remote sensing systems).

Notwithstanding the high per-vehicle cost of identifying gross polluters with remote sensing, the overall cost-effectiveness of the program, after accounting for the cost of confirmatory testing and repair of defective vehicles, may be in the range of US$15,000 per ton of HC+NOx emissions reduced. Although higher than average, this has been considered an acceptable ratio for other emissions control measures applied in California

In the two cases for which remote sensing is used only to determine average emissions from segments of the vehicle fleet, the corresponding annual operating costs were estimated to be $532,000 for 16 sites intermittently monitored by one manned remote sensing van (Scenario B-1) or $707,000 for 12 unmanned/permanent sites (Scenario B-2) intermittently equipped with one automated remote sensing system that is rotated between the sites. These calculated numbers of sites and remote sensing units and their associated costs may not scale linearly for metropolitan areas with a higher population because, although a wider geographic coverage would be required to ensure the representativeness of the sampling, the required sample size doesn’t change.

7. Future Program Options

As described in Section 6, there are wide variations in the features of I/M programs operating in North America with respect to network type, inspection frequency, range of vehicles tested, exhaust emissions test procedures, evaporative emissions test procedures, OBD testing procedures, repair cost limits, and enforcement methods. Each program involves periodic inspections at fixed locations using a centralized station network, decentralized station network, or some combination of the two. In some cases, there is an alternative, non-periodic inspection program element involving the use of remote sensing or remote OBD testing.

Table 20 summarizes our ranking of the various options for changing the current program. The symbols used in the table show how each program option compares to the current program. The symbol "○" indicates that the option is considered essentially equivalent to the current program. One or more plus symbols (+) indicates superior performance, and minus symbols (-) indicate inferior performance. An "x" indicates that the option isn't consider practical for a program beginning January 1, 2012. In addition to an overall ranking, rankings are provided from the perspective of motorists, environmental protection, and cost. The "environmental" category addresses protection of public health as well as regional, provincial, and federal objectives regarding the control of CAC, toxic, and GHG emissions. The cost category addresses the overall cost-effectiveness of the program in terms of dollars spent per tonne of emissions reduced.

7.1 Primary Program Options/Network Type

Centralized Testing – Since the current program already requires centralized testing, continuation of this approach is in the neutral category. Compared to decentralized or hybrid networks, centralized testing avoids the conflict of interest associated with inspections being done in facilities that are involved in the automotive service and repair business. The economies of scale associated with special purpose, drive-through test facilities also make it possible to use more expensive equipment, such as dynamometers capable of replicating stop-and-go driving, that improve the accuracy of the exhaust emissions tests.

Decentralized Testing – As described in Section 6, decentralized inspection networks have a poor track record with respect to testing accuracy. Despite intensive enforcement efforts, inaccurate and/or falsified test results have remained a problem in California for more than 20 years. The use of "undercover" operations to identify stations that produce inaccurate or falsified test results is only partially effective because of inspectors to treat vehicles owned by long time customers differently. Because of the poor economies of scale compared to high volume, centralized stations, decentralized testing also results in higher costs per test when dynamometers are required.

Table 20
Ranking of Program Options

Program Options/Strategies	Perspectives				**Overall Rating**
	Practicality	Motorist	Environmental	Cost-Effectiveness	
Primary Program Options (all with registration enforcement)					
Existing Centralized Network		○	○	○	○
Decentralized Test Network		+	– –	–	– –
Hybrid Test Network:					
A. Centralized Tailpipe Testing and Decentralized OBD Inspections		+	–	– –	– –
B. Kiosk Testing of Newer Fleet Vehicles, Centralized Testing of Other Vehicles		○	+	○	+
Remote OBD Monitoring for 1998+	**x**	+	+	–	**x**
Remote Sensing		+	– –	–	– –
Exhaust Test Procedures					
Continue ASM, IM240, and OBD-Only Based on Model Year		○	○	○	○
Convert to IM147, OBD w/ IM147 fallback for 1998+		○	+	○	+
Add Particulate Matter Testing Capability		○	+	○	+
Evaporative Test Procedures					
Continue Gas Cap Check for Pre-1998, OBD Check for 1998+		○	○	○	○
Add Liquid Leak Test for High HC Vehicles and Gas Cap Check for OBD Vehicles with Evap Monitor “Not Ready”		○	+	+	++
Inspection Frequency					
Continue Annual for Pre-1992, Biennial for Newer, Plus IM240 Random Sample		○	○	○	○
Annual for All		–	+	–	–
Biennial for Initial Passes, Annual for Initial Fails, Plus Expanded IM240 Random Sample with PM Testing		+	+	○	++
Vehicles Included					
Continue with All Light-Duty Vehicles >7 Years Old		○	○	○	○
All Light-Duty Vehicles >7 Years Old, Taxis >1 Year Old, Plus Change of Ownership for >2 Years Old		–	+	+	+
Repair Cost Ceilings					
Continue $300-600 for Pre-‘99, Unlimited for 1999 and Newer		○	○	○	○
$300-600 for Pre-1999, $900 for 1999 and Newer		+	–	+	+

Ratings: ++ Strongly positive; + Positive; ○ Neutral; – Negative; – – Strongly Negative; **x** Not viable

As shown in Table 20, decentralized testing has an overall rating in the "strongly negative" category when compared to the continuation of centralized testing. It offers increased convenience for vehicle owners who can have inspections performed at a larger number of locations, but it is less effective in reducing emissions and less cost-effective per tonne of emissions reduced.

<u>Hybrid Testing Networks</u> – Hybrid inspection networks, with a combination of centralized and decentralized inspection facilities, result in poorer economies of scale for the centralized stations (resulting in higher test costs and/or longer driving distances) along with the loss in program benefits associated with some of the inspections being conducted at centralized stations. To minimize the loss in emissions reductions, the decentralized option can be provided only for OBD equipped vehicles. There are fewer concerns with testing accuracy using OBD instead of a dynamometer test. However, this option reduces the cost-effectiveness of the program by reducing the economies of scale at centralized facilities. As shown in Table 20, we rank this option as strongly negative compared to the current centralized inspection network.

A hybrid option with an overall positive score involves the use of OBD kiosks to test newer fleet vehicles that would otherwise be exempt from the program because of the seven-year exemption.

<u>Remote OBD Monitoring</u> – Remote OBD monitoring is the alternative to periodic inspection programs with the greatest potential. However, this concept has not progressed beyond pilot-scale programs, except for fleet vehicles. If EPA or CARB were to require a standardized form of remote OBD monitoring capability in all new cars, this approach would become an attractive alternative, but the feasibility and cost-effectiveness of remote OBD monitoring on a retrofit basis remains unproven, except for fleet vehicles. Given the current status of the technology, there is insufficient lead time to consider this approach as a replacement for periodic testing beginning January 1, 2012.

<u>Remote Sensing</u> – As discussed in Section 6, remote sensing has fleet coverage limitations and other problems that preclude it as an alternative to periodic inspections at fixed locations. Motorists would probably prefer remote sensing over the current program because they would no longer be required to show up for periodic inspections. However, as a replacement for the current centralized program, remote sensing receives an overall rating of "strongly negative." Although remote sensing can be useful in for program enforcement and program evaluation purposes, there is no evidence that the cost of adding a routine remote sensing component to the AirCare program would be economically justified.

7.2 Exhaust Test Procedures

As indicated in Section 6, a variety of exhaust emissions test procedures are used in North American I/M programs. The most popular tests are idle; 2-speed idle (idle and 2500 rpm in neutral); the steady-state, loaded mode ASM 2525 and/or ASM 5015 tests; and the transient loaded mode IM240 test. Previous analyses have clearly demonstrated that the loaded mode tests are significantly more effective than the single and 2-speed idle tests. Among the loaded mode tests, the transient IM240 offers some advantage over the steady-state ASM tests in identifying vehicles with emissions-related defects. Table 21 indicates the percent of excess emissions identified using alternative tests based on a study previous conducted by Sierra for the U.S. EPA.[51]

Table 21
Excess Exhaust Emissions Identified

Test Procedure	HC	CO	NOx
IM240	98.6%	98.4%	97.0%
ASM	94.8%	93.5%	91.3%
Idle/2500 rpm	88.0%	80.7%	51.7%

A few I/M programs use a shortened version of the IM240 test procedure. The most effective of the shorter tests is the IM147 test, which consists of the last 147 seconds of the IM240. Sierra developed the IM147 test procedure under work conducted for the State of Arizona and U.S. EPA. The IM147 is routinely used in the Phoenix, Arizona program and is used in the AirCare program for Diesel opacity testing. The IM147 is as effective as the IM240 tests and takes less time to run, especially when using a fast pass algorithm.[52]

Replacing the ASM test (currently used for pre-1992 models) and the IM240 test (currently used for 1992-1997 models) with the IM147 test would significantly improve the effectiveness of the pre-1992 models and reduce the time required for testing all vehicles, especially with the use of a fast fail algorithm. It also offers the advantage of providing meaningful fuel economy/greenhouse gas estimates for pre-1992 models that are not possible with the ASM test. In addition, there is a slight cost savings associated with maintaining only one set of emissions analyzers in each test lane. Subjecting all vehicles to the same exhaust emissions test procedure may also seem more equitable to

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[51] P.L. Heirigs and T.C. Austin, “Analysis of Data from the California Enhanced I/M Pilot Program, Sierra Research Report No. SR95-06-01, June 29, 1995.

[52] R.W. Joy, P.L. Heirigs, G.D. Torgerson, M. St. Denis, T.C. Austin, J. Gordon, B. Tefft, and J. Linder, “Development of the IM147: An Alternative Inspection/Maintenance Mass-Emission Transient Test to Address Vehicle Preconditioning Concerns,” J. Air & Waste Management Association, 54: 269-285, March 2004.

the general public. (Continuing with full duration IM240 testing for a random sample would be best because of the better correlation with the Federal Test Procedure.)

Under the current program, 1998 and later model vehicles can pass an OBD inspection even if one monitor is "not ready." Additional emission reductions should also be achievable by requiring dynamometer testing of any vehicle with an exhaust-related OBD monitor that is not ready. Unless the vehicle can pass the dynamometer test, repairs would be required.

7.3 Evaporative Testing Procedures

Although the gas cap test currently being used is effective in identifying many vehicles with excessive evaporative emissions, a test for vehicles with liquid leaks would lead to further reductions in HC emissions. Consideration of a test for liquid leaks has been suggested in previous program reviews, but a practical and effective test procedure had not been demonstrated. However, as described in Section 6, it appears that a simple and effective test may now be available for use in test facilities equipped with constant volume sampling (CVS) systems. The proposed technique involves using a hydrocarbon "sniffer" to identify vehicles with liquid leaks when the sample being collected by the exhaust sampling systems detects a high hydrocarbon concentration. Pending more detailed analysis of this concept, it appears to have the potential to provide additional emission reductions in a cost-effective manner.

It would also appear to be worthwhile to use a functional check of the gas cap for any 1998 and newer vehicles that have an evaporative monitor "not ready."

7.4 Inspection Frequency

Under the current program, pre-1992 model vehicles require annual inspections regardless of how clean they were during their previous I/M test. In contrast, newer vehicles require only biennial testing, even when the previous I/M test indicated that they had been poorly maintained. When initially imposed, determining inspection frequency based on model year was reasonable because few 1992 and newer vehicles were old enough to have a high failure rate. Annual inspection frequency was justified for pre-1992 vehicles not only based on their age, but also because they were tested using a less effective exhaust emissions test procedure. In conjunction with a change to IM147 testing, older vehicles should arguably have the same opportunity to avoid annual inspection frequency by proving they were in good repair when initially tested. The minor loss in emissions benefits can be made up by requiring annual testing for 1992 and newer models that fail their initial test.

Expanded IM240 Testing – Subjecting a random sample of vehicles to full-duration IM240 testing provides a valuable source of information regarding the average emissions of the motor vehicle fleet. Under the current program, 1998 and newer vehicles that pass the OBD inspection are exempted from the random sample. This was a reasonable time-saving measure when there were relatively few 1998 and newer models subject to inspection and when it was likely that the IM240 emissions of passing vehicles were very likely close to zero. However, as the fleet ages, 1998 and later model vehicles, especially those with “not ready” OBD monitors, cannot be assumed to be near zero emissions. There is now value in adding them to the random sample.

We also see benefits to adding particulate measurement to the testing of the random sample. With increasing emphasis on reducing motor vehicle fuel consumption and greenhouse gas emissions, it is likely that an increasing fraction of the light-duty vehicle fleet will be equipped with Diesel engines. Although emissions standards for new Diesel-powered vehicles require effective control of particulate emissions, the opacity test in the current AirCare program is inadequate for determining the effectiveness of modern Diesels equipped with particulate filters. In addition, the current program is incapable of detecting gasoline vehicles with high particulate emissions unless they are visibly smoking.

There is not sufficient evidence that it would be cost-effective to add a particulate emissions test to the AirCare program. However, because of the growing recognition that particulate emissions are a more important source of air pollution than previously recognized, it would be useful to begin collecting particulate emissions data on a random sample of vehicles. At a minimum, this would improve the accuracy of the vehicle emissions inventory. The testing could be terminated if it is determined that the fraction of the fleet with excessive emissions is too small to be cost-effectively controlled through the implementation of routine inspections. If, however, testing indicates that routine PM testing would identify vehicles with excessive emissions that can be cost-effectively repaired, the feasibility and cost of incorporating routine PM testing can be evaluated.

7.5 Vehicles Included

Under the current program, new vehicles are exempt from testing until they are eight years old. As summarized below, there are a couple of changes to this exemption that would improve the effectiveness of the program.

Change of Ownership Testing – One of the significant benefits of I/M programs is that they deter motorists from removing or otherwise tampering with emissions control systems. However, in conjunction with the seven-year exemption for new vehicles, the lack of change of ownership testing makes it possible for the owners of relatively new vehicles to tamper with emissions control systems with virtually no risk of penalty if they intend to sell the vehicle before it is eight years old. The requirement for vehicles to be inspected upon change of ownership would have three benefits. First, it would often require the repair of tampered vehicles sooner. Second, it would serve as a deterrent to tampering in the first place by making owners responsible for the repair of any tampering they might be inclined to do. Third, it provides a measure of consumer protection for the purchasers of used vehicles who subsequently become obligated to correct tampering when the vehicle becomes subject to the AirCare program.

Taxicab Testing – Many emissions-related defects occur in taxicabs during the seven-year exemption period because of the extremely high rate of mileage accumulation typical of taxicab service. Many cabs are essentially worn out before they become subject to testing under the current program. The limited data available on taxicabs tested after seven years indicate that they have extraordinarily high emissions before they become subject to AirCare repair requirements. Based on the available data regarding emissions and mileage accumulation, the new-vehicle exemption for taxicabs should be reduced to one year. At age two, the average cab has already accumulated as many kilometers as the average privately owned vehicle.

7.6 Repair Cost Ceilings

The repair cost limits are the maximum the owner of a failed vehicle is required to spend if the repairs are performed by a certified repair technician working at a certified repair centre. Under the current program, pre-1999 models have repair cost limits ranging from $300 to $600, depending on vehicle age, but there is no repair cost limit for 1999 and newer vehicles. The oldest of the 1999 and newer vehicles has reached the point where some repairs required to pass an OBD test may exceed the value of the vehicle while resulting in relatively little emissions benefit. This is especially a concern with vehicles certified to Low Emission Vehicle standards that have experienced a relatively minor loss in catalyst efficiency. To improve the cost-effectiveness of the program and to reduce the economic burden on vehicle owners, it is recommended that a $900 repair cost ceiling be applied to vehicles that have relatively low emissions on an IM147 dynamometer test and can pass a gas cap functional test. Additional repair costs would be required only for vehicles that are gross polluters.

7.7 Effectiveness and Cost-Effectiveness of Potential Program Changes

Table 22 presents our estimates of how the current program compares to the proposed alternative program in calendar year 2020. As with the estimates for the current program shown in the previous section, we have developed one set of estimates using the MOBILE6.2C model without any modifications; a second set of estimates incorporates an adjustment to the model to account for what we believe to be an underestimate of emissions in the absence of an I/M program.

Without modification, the MOBILE model predicts that a continuation of the current program would reduce impact-weighted emissions by 8,109 tonnes in 2020, which represents a 22.6% reduction from what emissions are projected to be in the absence of an I/M program. Using our revised estimates for emissions in the absence of an I/M program, the reduction in impact-weighted emissions increases to 16,028 tonnes, which is 36.6% below our alternative estimate for emissions in the absence of an I/M program.

Table 22
Annual Light-Duty Vehicle Emissions in the LFV With and Without AirCare

	Column A	Column B	Column C	Column D		Column E	
Year and Pollutant	No-I/M Per MOBILE	No-I/M Revised Model	With I/M	Emission Reduction Per MOBILE (A vs. C)		Emission Reduction Revised Model (B vs. C)	
	tonnes	tonnes	tonnes	tonnes	%	tonnes	%
2010 w/Current I/M Program							
VOC	12,744	13,653	11,092	1,653	13.0%	2,562	18.8%
CO	189,220	206,947	159,237	29,982	15.8%	47,710	23.1%
NOx	11,966	13,010	10,268	1,699	14.2%	2,743	21.1%
Impact-Weighted*	51,742	56,228	44,107	7,635	14.8%	12,120	21.6%
2020 w/Current I/M Program							
VOC	6,995	8,600	5,208	1,787	25.6%	3,393	39.4%
CO	157,183	187,791	126,527	30,657	19.5%	61,264	32.6%
NOx	6,430	8,372	4,489	1,942	30.2%	3,883	46.4%
Impact-Weighted	35,880	43,800	27,772	**8,109**	**22.6%**	**16,028**	**36.6%**
2020 w/ Modified **I/M Program**							
VOC	6,995	8,600	4,120	2,876	41.1%	4,481	52.1%
CO	157,183	187,791	125,057	32,126	20.4%	62,734	33.4%
NOx	6,430	8,372	4,375	2,055	32.0%	3,997	47.7%
Impact-Weighted	35,880	43,800	26,360	**9,520**	**26.5%**	**17,440**	**39.8%**

*VOC+(CO/7)+NOx

The bottom section of the table shows or estimates for the alternative I/M program using the proposed changes described above.[53] The most significant change is the increase in

HC emissions reductions estimated for the addition of a test for liquid leakers. We assumed half of the liquid leakers would be identified and repaired. Using the unmodified version of the MOBILE model, impact-weighted emissions are reduced by 9,520 tonnes in 2020, which is a reduction of 26.5%. Using our revised estimates for emissions in the absence of an I/M program, the reduction in impact-weighted emissions increases to 17,440 tonnes, which is 39.8% below our alternative estimate for emissions in the absence of an I/M program.

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[53] Annual testing for vehicles that are initial fails was modeled based on the assumption that this approach would provide 90% of the benefits of annual testing. This assumption is supported by an analysis showing that a disproportionate fraction of failing vehicles failed in the previous I/M cycle; i.e., vehicles that are initial test failures are much more likely to be failures in a subsequent cycle than vehicles that are initial test passes.

To avoid complicating the table, greenhouse gases are not shown and only two calendar years are shown. Detailed modeling results, in five year increments from 2005 through 2020, are provided in Appendix C. The detailed results include GHGs, but not toxics. The reduction in toxic emissions associated with the continuation of the AirCare program is roughly proportional to the reduction in VOC (e.g., 25-52% depending on the modeling assumptions used. (A more detailed analysis of toxics also presented in Appendix C.)

As shown in Appendix C, the reduction in GHG emissions is 1.1%. (This is the direct benefit and does not include indirect benefits that may result from providing motorists with information regarding how the GHG emissions of their particular vehicle compare to other vehicles.)

Assuming testing costs remain constant, the cost-effectiveness associated with continuation of the current program or implementation of a modified program in 2020 will depend on the cost of the emissions-related maintenance the program will require that would not otherwise be done in the absence of an IM program. The cost estimate presented previously for the current program in 2010 was based on the assumption that 18% of the inspected vehicles would require an average of $428 in additional maintenance cost every two years. Assuming the average repair cost increases in proportion to the benefits of the modified program, the cost per vehicle per inspection cycle would be calculated as follows:

$$\begin{aligned}\text{Cost/Vehicle} &= \$45 + (0.104 \times \$23) + (0.18 \times \$466) - (0.011 \times \$3{,}000)\\ &= \$45 + \$1.35 + \$83.88 - \$33\\ &= \$97.23\end{aligned}$$

Where: $45 is the initial inspection cost incurred in two years

0.104 is the fraction of vehicles that fail and return for a re-inspection

$23 is the re-inspection cost

0.18 is the fraction of the inspected vehicles requiring
Pre-inspection maintenance or maintenance after failing

$466 is the average repair cost

(0.011 × $3,000) is the fuel cost savings

Based on the estimated 2010 vehicle population, the annual cost projection would be $44.2 million. Assuming continuation of a 1.25% population growth rate, the annual cost increases to $50 million by 2010. Based on the 17,440 tonne impact-weight emission reduction from Table 22, the cost-effectiveness ratio for our alternative estimate of the alternative program is $2,867 per tonne, which is lower than the 2010 ratio. Based on the unadjusted MOBILE model results, the 9,520 tonne reduction produces a cost-effectiveness ratio of $5,252 per tonne, which is almost identical to the 2010 ratio.

7.8 Cost-Effectiveness of Other Control Measures

To put the cost-effectiveness estimates in context, they can be compared to estimates for other emissions control programs. Since it is common for cost-effectiveness estimates to be based on HC or NOx or HC+NOx, the cost-effectiveness of the AirCare program can be calculated based on only HC and NOx to facilitate comparison. For our alternative estimate, the cost-effectiveness of the proposed AirCare program in 2020 would be $5,898 per tonne of HC+NOx. Based on unadjusted MOBILE output, the cost-effectiveness would be $10,140 per tonne.

The cost-effectiveness of other emissions control measures has been evaluated previously by both Metro Vancouver and other agencies with responsibility of the implementation of air pollution control measures. A 2005 report for Metro Vancouver by Crane Management Consultants provides a summary of previous analyses.[54]

As shown in the Crane report, there are extreme variations in the cost-effectiveness ratio for various emissions control measures. At one end of the spectrum, a few measures have been estimated to actually result in a cost savings while simultaneously providing a reduction in emissions. Referencing a 2004 report by Levelton Consultants, the Crane report lists a cost savings of $1,100 to $10,800 per tonne for the use of Diesel fuel additives. Referencing a 2004 report on the San Francisco Bay Area Ozone Strategy, zero cost is assigned to the required use of a low-solvent paint for automotive refinishing operations.

At the other end of the spectrum are a number of emissions control measures estimated to cost substantially more than $10,000 per tonne of HC+NOx. For example, the Crane report attributes an estimate of $42,900 to $137,900 per tonne to “E-Diesel,” a blend of 7.7% ethanol and Diesel fuel. The report attributes an estimate to the South Coast Air Quality Management District of $20,000 per ton for a rule affecting architectural coatings.

Intermediate-range cost-effectiveness values in the Crane report are attributed to the “Ontario Industry Emissions Reduction Plan” and include the application of selective catalytic NOx reduction systems to sources in the petro-chemical and refining industry at $7,300 - $18,000 per tonne; low NOx burners at $2,000 - $5,500 per tonne; process controls in cement manufacturing at $11,000 - $25,000 per tonne of NOx.

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[54] Derek De Biasio, “Socio-Economic Considerations of Cleaning Greater Vancouver’s Air,” Crane Management Consultants, August 2005.

The California Air Resources Board fhas estimated very low costs for a variety of control measures adopted in the past; however, costs are significantly higher to achieve incremental reductions. CARB has recently made estimates for a number of HC and NOx control measures proposed for adoption as a part of the 2007 State Implementation Program in California.[55] Making the appropriate conversion to 2010 Canadian dollars and metric tonnes, the estimated costs of the California control measures are as follows:

Recreational Boat New Standards:	$5,847
Clean Up Existing Harbor Craft:	$6,105
Consumer Products:	$5,966
Cleaner Ship Engines and Fuels:	$9,952
Cleaner Line-Haul Locomotives:	$12,399
Old Vehicle Retirement:	$14,051
Off-Road Recreational Evaporative:	$16,461
Cleaner In-Use Off-Road Equipment:	$16,425
Reformulated Gasoline Program:	$17,528
Cleaner In-Use Heavy-Duty Trucks:	$39,094
Port Truck Modernization:	$40,013
Auxiliary Ship Engine Cold Ironing:	$52,717

Under the current effort, the estimated cost-effectiveness of the AirCare program has also been compared to the cost-effectiveness of obtaining additional emissions reductions through the use of transit system improvements, including shuttles, paratransit, new capital systems/vehicles, conventional service upgrades, and park-and-ride lots. The primary reference document used in the evaluation was a 2002 report prepared by the Transportation Research Board (TRB)[56] which provided a critical evaluation of the Congestion Mitigation and Air Quality Improvement Program, commonly referred to as CMAQ (pronounced see′-mac). The report addressed whether projects funded under the program were effective and cost-effective relative to alternative strategies for achieving air quality goals. More than 80 source documents were referenced in support of the estimates provided for the costs and emissions benefits of the various measures evaluated.

The following projects are eligible for CMAQ funding:

- Improvements to public transit service, including new and replacement vehicles;
- New transit stations, terminals, transit centers or malls, intermodal transfer facilities, and park-and-ride facilities;

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[55] http://www.arb.ca.gov/planning/sip/2007sip/apr07draft/revdrftappe.pdf

[56] "The Congestion Mitigation and Air Quality Improvement Program, Assessing 10 Years of Experience," Special Report No. 264, Committee for the Evaluation of the Congestion Mitigation and Air Quality Improvement Program, Transportation Research Board, National Research Council, 2002.

- Fringe and corridor parking facilities serving transit or multi-occupant vehicle use; and

- Short-term promotional subsidies of transit/paratransit fares.

As explained in a very detailed appendix to the TRB report, both costs and emission benefits were discounted to a net present value to account for changes in benefits over the life span of the investment.

The cost-effectiveness estimates contained in the TRB report do not account for reductions in CO emissions. It is noted that information on CO emissions reductions for transportation improvement projects is often not reported because most CMAQ projects "are primarily to reduce regional ozone, and they have little impact on localized CO hot spots."

Another complication of the TRB analysis is that the cost-effectiveness values summarized in the body of the report are based on the application of a 4.0 weighting factor to reductions in NOx emissions. In explaining the reasons for the weighting factor, the report states that a higher weight for NOx is "justified by its importance in many areas' efforts to attain or maintain ozone standards." Given the concern about the ineffectiveness of NOx controls on ozone air quality in the Lower Fraser Valley, the higher weighting factor does not appear to be justified for the region. Fortunately, the appendix to the TRB report contains cost-estimates with equal weighting applied to HC and NOx. We have therefore used the estimates based on equal weighting for HC and NOx.

<u>Shuttles, Feeder, Paratransit</u> – Estimates of the cost-effectiveness of shuttles and/or feeder services were based on estimated costs and emissions reductions for 15 separate projects located throughout the U.S. The median cost-effectiveness ratio for the 15 projects, when converted to 2010 Canadian dollars[57] and metric tonnes, was $256,000 per tonne. However, review of the detailed tables in the appendix of the TRB report indicates that there was a wide variation in cost-effectiveness ratio between the projects. The least expensive project was a Pace VIP transit van project (apparently serving the Chicago suburbs). Using the estimated reductions in HC and NOx emissions associated with the Pace transit van project, we have independently calculated the cost-effectiveness without the 4.0 multiplier applied to NOx emissions to be $92,000/tonne.

<u>New Transit Capital Systems/Vehicles</u> – Estimates of the cost-effectiveness of new transit systems and/or vehicles were based on estimated costs and emissions reductions for six separate projects, which included four rail projects, a ferry, and bus rapid transit

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[57] Dollar values in the TRB report were adjusted from 2000 calendar year to 2010 calendar year by a factor of 1.263 to account for changes in the U.S. Consumer Price Index and by a factor of 1.04 to convert U.S. dollars to Canadian dollars.

system in Ottawa called "TransitWay." The median cost-effectiveness ratio for the six projects, when converted to 2010 Canadian dollars and metric tonnes, was $248,000 per tonne. As was the case with the shuttle projects, review of the detailed tables in the appendix of the TRB report indicates that there was a wide variation in cost-effectiveness ratio between the projects. The Ottawa TransitWay project was the least expensive of the six. Using the estimated reductions in HC and NOx emissions associated with the Ottawa TransitWay project, we have independently calculated the cost-effectiveness without the 4.0 multiplier applied to NOx emissions to be $27,000/tonne.

<u>Conventional Transit Service Upgrades</u> – Estimates of the cost-effectiveness of conventional transit system upgrades were based on estimated costs and emissions reductions for 10 separate projects, which ranged from a "traveler information system" to increased frequency/reduced headway for rail and bus systems. The median cost-effectiveness ratio for the 10 projects, when converted to 2010 Canadian dollars and metric tonnes, was $77,000 per tonne. As was the case with other types of projects, review of the detailed tables in the appendix of the TRB report indicates that there was a wide variation in cost-effectiveness ratio between the projects. The least expensive project involving (suburban bus) service improvements was $59,000/tonne on HC+NOx.

<u>Park and Ride Lots</u> – The single estimate for the cost-effectiveness of park and ride lots at transit stations translates to $179,000/tonne when converted to 2010 Canadian dollars and metric tonnes.

Table 23 summarizes the estimated cost-effectiveness values for transit-related projects extracted from the TRB report and compares them to cost-effectiveness estimates for I/M programs. As shown in row 8 of the table, the TRB report estimates the cost-effectiveness of I/M at $5,373/tonne when only HC and NOx are considered. This is reasonably close to Sierra's independent estimate[58] of $3,600/tonne for the cost-effectiveness of the AirCare program for HC+NOx only in calendar year 2005, which is shown in row 9 of the table. As shown in row 10, our current estimate of AirCare program is higher at $7,729 for HC+NOx only because of the lower average emissions of the vehicles subject to the program. However, as shown in row 11, we estimate a reduction in the cost-effectiveness ratio to $5,898 with the revisions that have been proposed for the next generation of the AirCare program. All of the I/M program cost-effectiveness estimates are significantly lower than various transit system improvements.

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[58] T.C. Austin, et al., "Factors Affecting the Cost and Effectiveness of Motor Vehicle Inspection and Maintenance Programs," June 9, 2006.

Table 23
Cost-Effectiveness Estimates for Transit System Improvements Compared to I/M (CDN$/tonne of HC + NOx)

Measure	$/tonne
1. Shuttles, feeder, paratransit (general)	$256,000
2. Pace (Chicago) transit van project	$92,000
3. New transit capital systems/vehicles (general)	$248,000
4. Ottawa TransitWay (bus)	$27,000
5. Conventional transit service upgrades (general)	$77,000
6. Suburban bus system improvements	$59,000
7. Park-and-ride lots at transit stations	$179,000
8. TRB estimate for I/M	$5,373
9. Sierra’s Independent Estimate of AirCare, circa 2005	$3,600
10. Sierra’s Independent Estimate of AirCare, circa 2010	$7,729
11. Sierra’s Independent Estimate of Revised AirCare Program	$5,898

8. Air Quality Benefits of Continuing AirCare

8.1 Revised Estimates of Trends in LDV Emissions

Based on the emissions modelling analyses presented in Appendix C, this section provides a summary of revised estimates in emission trends from 2005 to 2020 for light-duty vehicles which differ from those presented in Section 3. Tables 24, 25, and 26 provide a comparison between the following five emission scenarios:

1. Emissions based on the 2005 emission inventory prepared by Metro Vancouver as summarized in Section 3;
2. Baseline emissions using the existing MOBILE6.2C model without the AirCare program (Scenario 1);
3. Modified baseline emissions without the AirCare program (Scenario 2);
4. Emissions based on the current AirCare program (Scenario 3); and,
5. Emissions based on an alternative AirCare program (Scenario 4).

Comparisons in LDV emission estimate trends for CO, NOx, SO_2, VOC, $PM_{2.5}$ and GHG in these five scenarios are discussed below and are presented graphically in Figures 26 through 31.

Table 24
LDV Emission Trend Scenarios for 2005 and 2010

	Emission Estimates (tonnes/year)							
	2005			**2010**				
I/M Case	**MV Forecast**	**None**	**Current**	**MV Forecast**	**None, MOBILE No I/M Baseline**	**None, Revised Model No I/M Baseline**	**Current AirCare**	**Modified AirCare**
	LDV							
VOC	15797	19257	16584	11085	13001	13910	11348	8983
CO	197402	263937	213796	150346	190451	208178	160468	159135
NOx	13006	16712	14480	9323	12236	13280	10537	10445
$PM_{2.5}$	152	148	148	147	134	134	134	134
SO_2	81	85	85	96	103	103	103	103
NH_3	1089			1194	1211	1211	1211	1211
CO_2	5015195	5104026	5030186	4896864	5307554	5307554	5242249	5235926
N_2O	676	339	333	546	228	228	228	227
CH_4	377	703	703	310	513	513	513	513
CO_2eq	5232813	5322146	5248157	5072666	5466156	5466156	5400847	5394499

Table 25
LDV Emission Trend Scenarios for 2015 and 2020

	Emission Estimates (tonnes/year)									
	2015					2020				
I/M Case	MV Forecast	None, MOBILE No I/M Baseline	None, Revised No I/M Baseline	Current AirCare	Modified AirCare	MV Forecast	None, MOBILE No I/M Baseline	None, Revised No I/M Baseline	Current AirCare	Modified AirCare
	LDV									
VOC	8698	8895	10171	7311	5747	6620	7165	8771	5378	4290
CO	157753	162661	186827	134977	133698	149904	158656	189264	128000	126530
NOx	7708	8764	10318	7062	6958	5696	6568	8509	4626	4512
$PM_{2.5}$	147	130	130	130	130	152	134	134	134	134
SO_2	103	112	112	112	112	109	120	120	120	120
NH_3	1277	1295	1295	1295	1295	1359	1379	1379	1379	1379
CO_2	4541975	5303073	5303073	5243984	5239587	4168215	5168453	5168453	5114073	5110445
N_2O	435	172	172	169	169	372	147	147	147	147
CH_4	265	399	399	399	399	234	373	373	373	373
CO_2eq	4682515	5426418	5426418	5367272	5362874	4288314	5283203	5283203	5228818	5225190

Table 26
Summary of LDV Emission Trend Scenarios for Selected Air Toxics

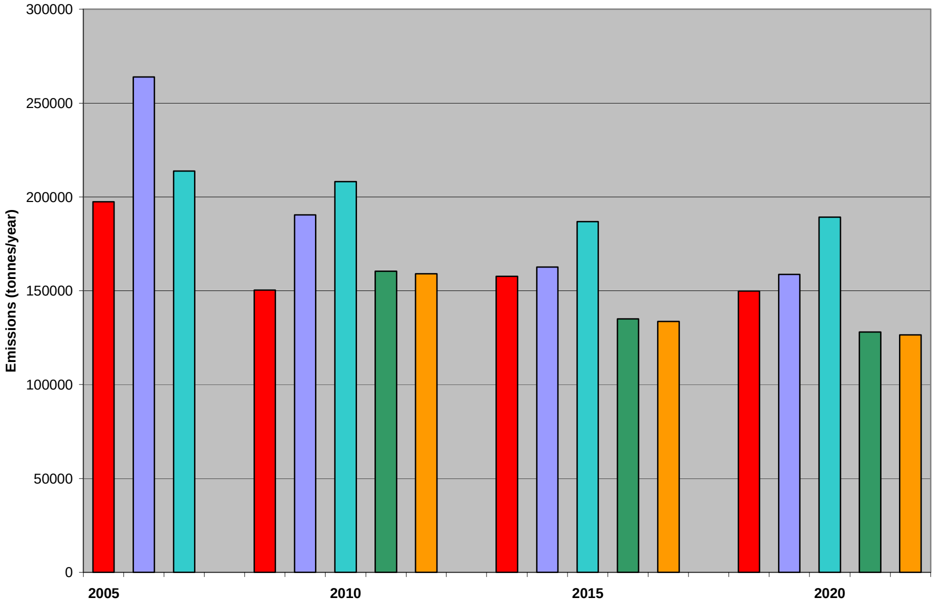
I/M Case	% GLL Inclusion	Species	Annual Emissions (tonnes/year) 2005	2010	2015	2020
None, MOBILE No I/M Baseline	100%	Exhaust Benzene	517.8	334.0	258.8	236.1
		Evaporative Benzene	42.3	34.5	22.3	15.1
		Total Benzene	560.2	368.4	281.1	251.2
		Exhaust Acetaldehyde	70.1	43.8	31.4	28.9
		Exhaust Acrolein	7.9	5.1	3.8	3.4
		Exhaust Butadiene	88.0	52.4	35.4	32.4
		Exhaust Formaldehyde	203.5	122.3	84.3	77.6
None, Modified No I/M Baseline	100%	Exhaust Benzene		379.3	327.9	323.1
		Evaporative Benzene		34.5	22.3	15.1
		Total Benzene		413.8	350.2	338.1
		Exhaust Acetaldehyde		47.5	35.5	33.7
		Exhaust Acrolein		5.5	4.4	4.3
		Exhaust Butadiene		52.4	35.4	32.4
		Exhaust Formaldehyde		122.3	84.3	77.6
Current	100%	Exhaust Benzene	403.4	255.5	182.1	148.5
		Evaporative Benzene	41.6	33.7	21.4	14.1
		Total Benzene	445.0	289.2	203.5	162.5
		Exhaust Acetaldehyde	54.8	35.1	23.2	19.6
		Exhaust Acrolein	6.2	4.1	2.7	2.3
		Exhaust Butadiene	68.9	41.5	25.2	20.6
		Exhaust Formaldehyde	159.5	99.5	62.9	53.2
Modified	50%	Exhaust Benzene		251.6	178.1	143.7
		Evaporative Benzene		21.1	13.3	8.7
		Total Benzene		272.7	191.4	152.4
		Exhaust Acetaldehyde		34.7	22.8	19.1
		Exhaust Acrolein		4.0	2.7	2.3
		Exhaust Butadiene		41.0	24.7	20.0
		Exhaust Formaldehyde		98.2	61.7	51.9

Note: GLL- Gross Liquid Leakers

8.1.1 LDV Emission Trends – As indicated in Figures 26, 27 and 29, AirCare has a significant effect on reducing emission of CO, NOx, and VOC from light-duty vehicles, but no effect on SO_2 or $PM_{2.5}$ emissions (Figures 28 and 30) and only a limited effect on reducing GHG emissions (Figure 31). Metro Vancouver's estimates of CO, NOx, and VOC to 2020 somewhat underestimated the baseline emission estimates, but overestimated emissions for the current AirCare program. Figures 26 and 27 show that although there is an additional small benefit in reduced CO and NOx emissions for the modified AirCare program as compared with the current AirCare program, the greatest benefit of the modified AirCare program is in reducing VOC emissions.

Figures 28 and 31 indicate that Metro Vancouver somewhat underestimated the LDV SO_2 and GHG emissions, but overestimated $PM_{2.5}$ emissions (Figure 30) in the 2005 emission inventory.

Figure 26
Comparison of Trends in LDV CO Emissions



Emission scenario colour key:

🟥	2005 emission inventory by Metro Vancouver
🟪	None, MOBILE No I/M Baseline
🟦	None, Modified No I/M Baseline
🟩	Current AirCare
🟧	Modified AirCare

Figure 27
Comparison of Trends in LDV NOx Emissions

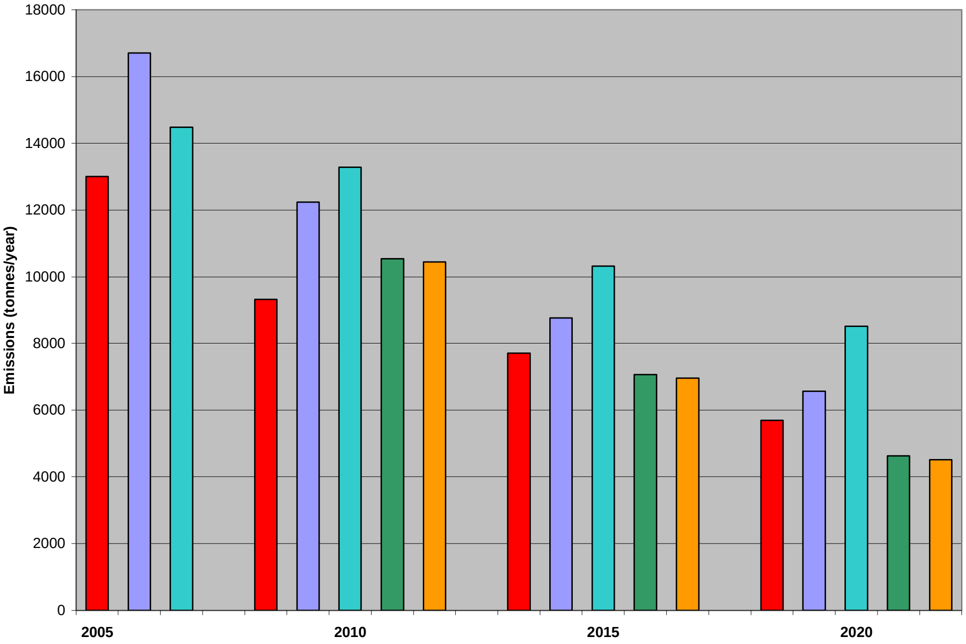
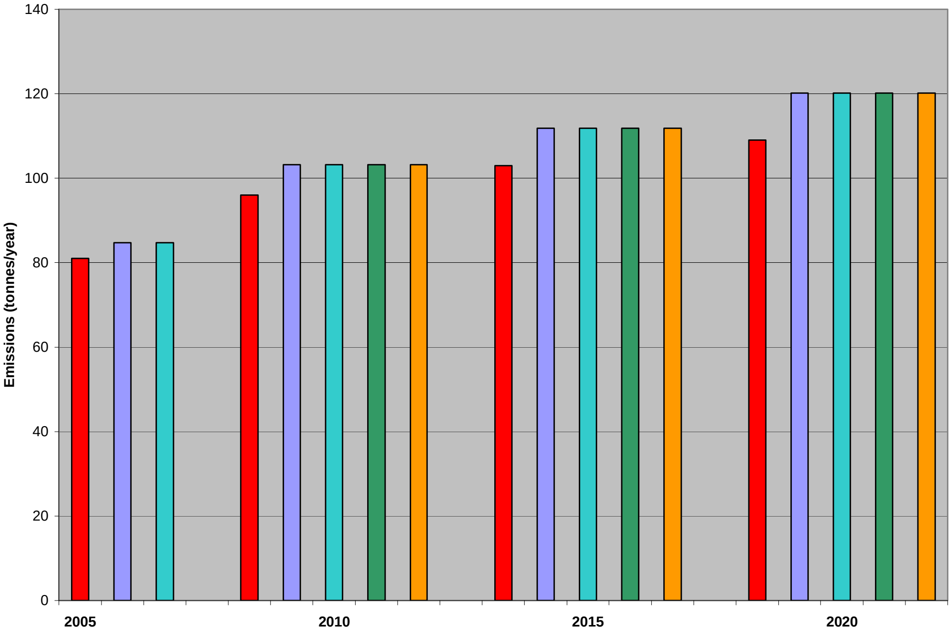


Figure 28
Comparison of Trends in LDV SO_2 Emissions



Emission scenario colour key:

🟥	2005 emission inventory by Metro Vancouver
🟪	None, MOBILE No I/M Baseline
🟦	None, Modified No I/M Baseline
🟩	Current AirCare
🟧	Modified AirCare

Figure 29
Comparison of Trends in LDV VOC Emissions

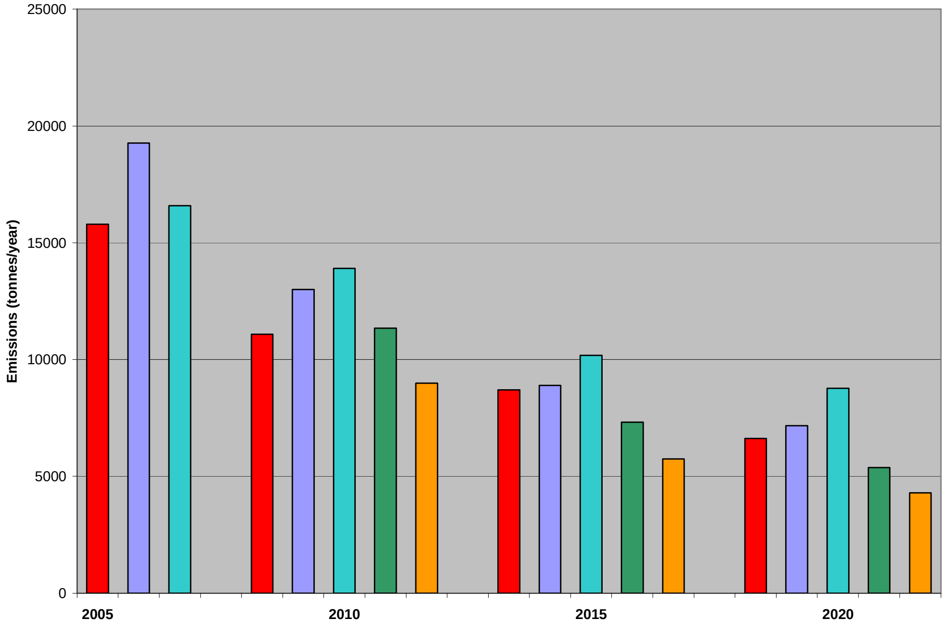
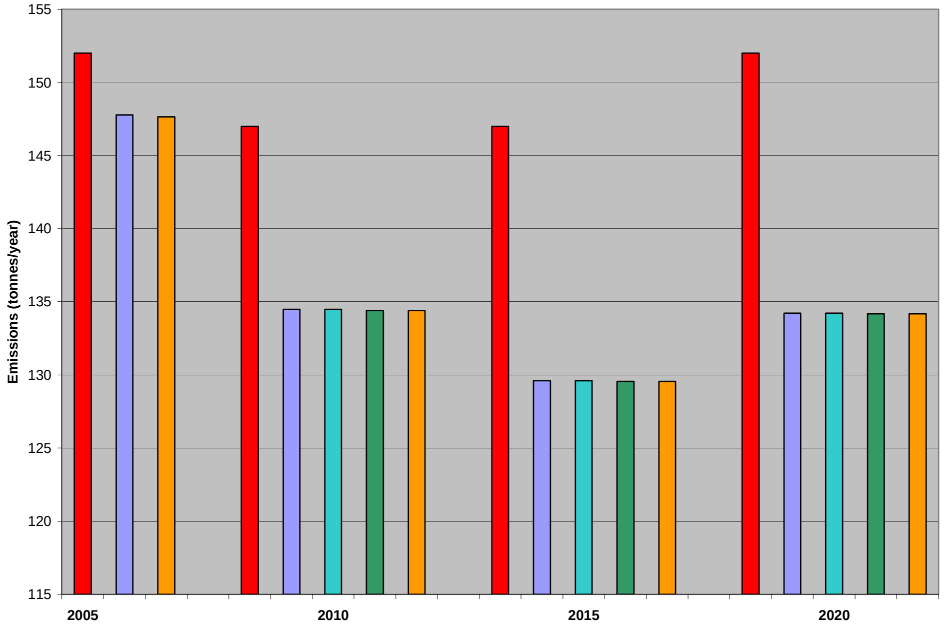


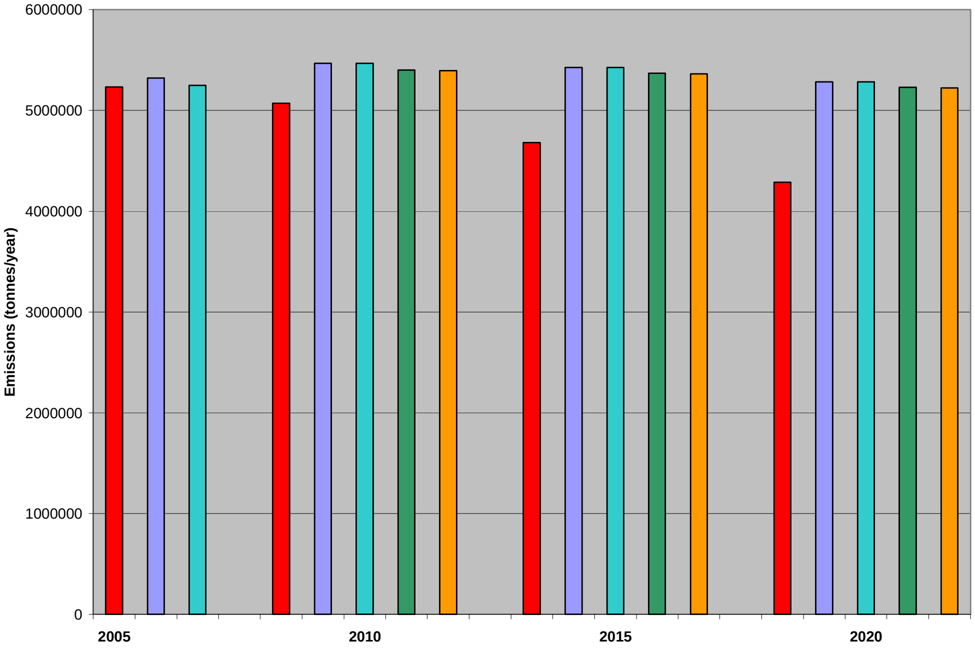
Figure 30
Comparison of Trends in LDV $PM_{2.5}$ Emissions



Emission scenario colour key:

🟥	2005 emission inventory by Metro Vancouver
🟪	None, MOBILE No I/M Baseline
🟦	None, Modified No I/M Baseline
🟩	Current AirCare
🟧	Modified AirCare

Figure 31
Comparison of Trends in LDV GHG Emissions



Emission scenario colour key:

🟥	2005 emission inventory by Metro Vancouver
🟪	None, MOBILE No I/M Baseline
🟦	None, Modified No I/M Baseline
🟩	Current AirCare
🟧	Modified AirCare

8.1.2 LDV Emission Trends for Selected Air Toxics

In 2001, the U.S. EPA listed 21 toxic air pollutants associated with motor vehicle emissions as compounds or compound classes of particular concern to human health (http://epa.gov/otaq/toxics.htm). These were referred to as Mobile-Source Air Toxics (MSATs), and are listed below.

Acetaldehyde
Acrolein
Arsenic
Benzene
1,3-Butadiene
Chromium compounds
Diesel engine exhaust
Dioxins and furans
Ethylbenzene
Formaldehyde
Hexane
Lead compounds
Manganese compounds
Mercury compounds
Methyl tert-butyl ether (MTBE)
Naphthalene
Nickel compounds
Polycyclic organic matter (POM)
Styrene
Toluene
Xylene

The EPA's choice on which compounds to include in the list of 21 MSATs was based on (1) those compounds that originate at least in part from mobile sources, and (2) taking into account health and risk assessment information contained in the Integrated Risk Information System (IRIS). It should be noted that the EPA does not classify NO_2, SO_2, PM_{10} or $PM_{2.5}$ as toxic compounds, but these compounds are considered toxic compounds under the Canadian Environmental Protection Act (CEPA). It should also be noted that not all of these substances are associated with Diesel fuel, and some, like manganese and MTBE, are more associated with gasoline and gasoline additives.

In 2007, the EPA further refined this list of MSATs to define eight priority toxic compounds:

Acetaldehyde
Acrolein
Benzene
1,3-Butadiene
Formaldehyde

Naphthalene
Polycyclic organic matter (POM)
Diesel exhaust (both organic gases and particulate matter)

Of these, only acetaldehyde, acrolein, benzene, 1,3-butadiene and formaldehyde are associated with gasoline-fueled light-duty vehicles. Table 26 (shown previously) provides a summary of the expected changes in the emission rates for these five toxic compounds, while Figures 32 to 36 depict the trends in the LDV emissions of these five selected air toxics in the LFV from 2005 to 2020. The figures show decreasing trends in the emissions of all five substances from levels in 2005, with larger decreases occurring with either the current or the modified AirCare program.

Figure 32
Comparison of Trends in LDV Benzene Emissions

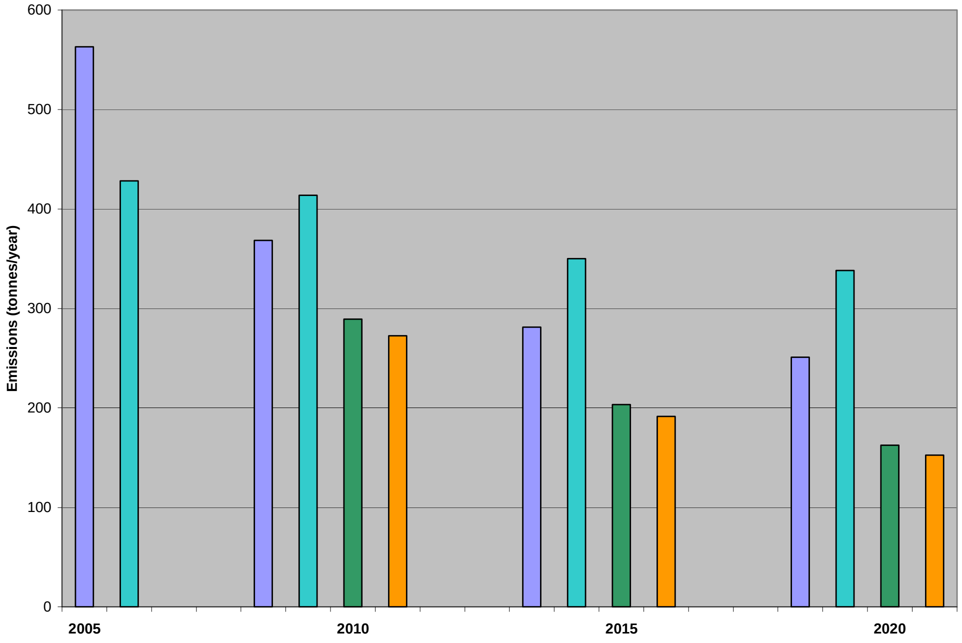


Figure 33
Comparison of Trends in LDV Acetaldehyde Emissions

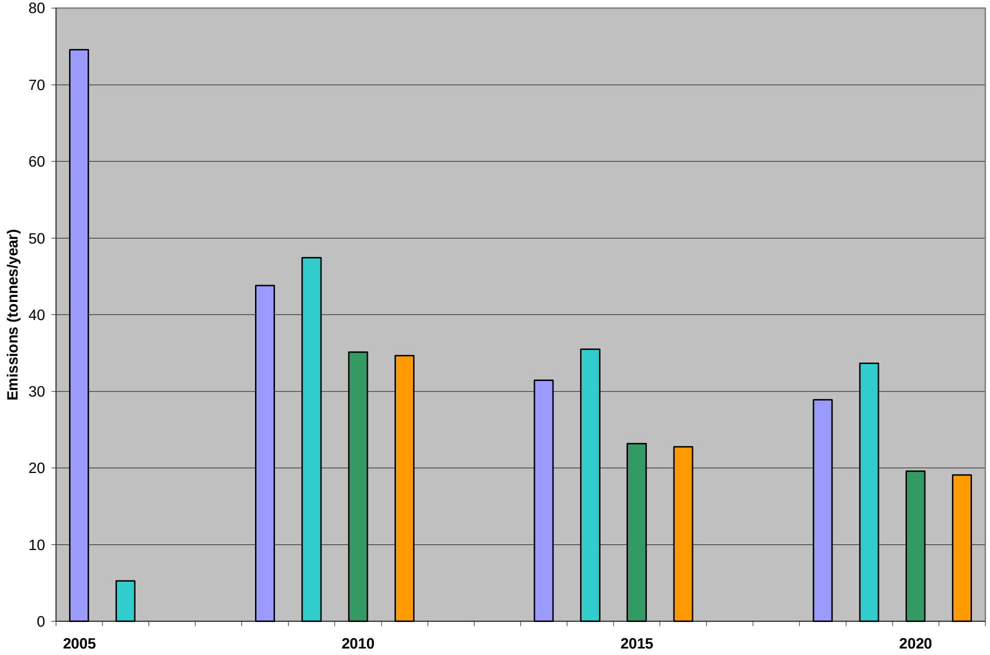
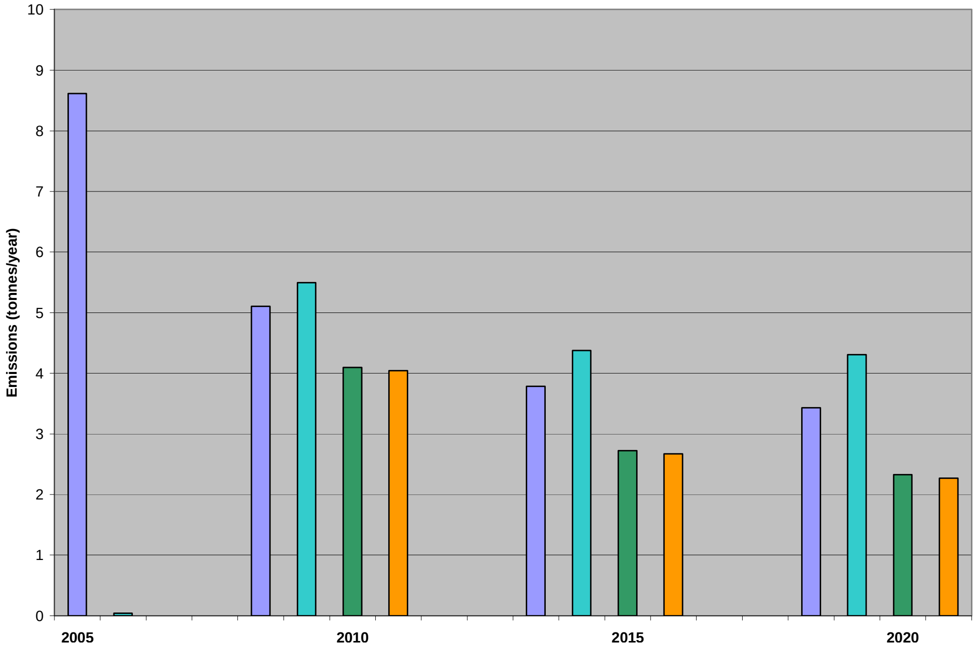


Figure 34
Comparison of Trends in LDV Acrolein Emissions



Emission scenario colour key:

🟪	None, MOBILE No I/M Baseline
🟦	None, Modified No I/M Baseline
🟩	Current AirCare
🟧	Modified AirCare

Figure 35
Comparison of Trends in LDV 1,3-Butadiene Emissions

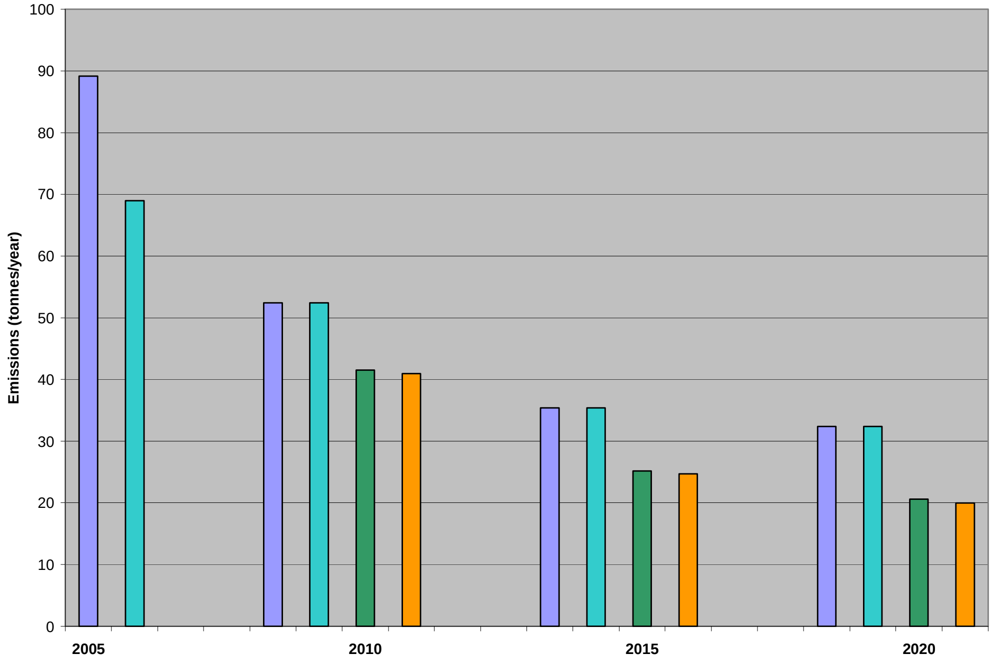
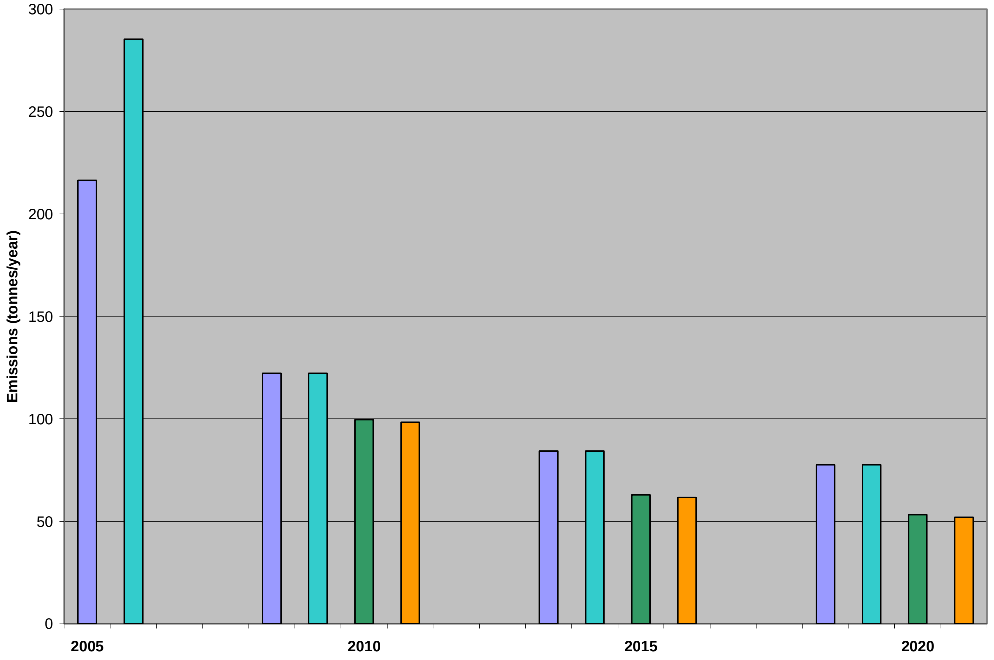


Figure 36
Comparison of Trends in LDV Formaldehyde Emissions



Emission scenario colour key:

🟪	None, MOBILE No I/M Baseline
🟦	None, Modified No I/M Baseline
🟩	Current AirCare
🟧	Modified AirCare

8.2 Effects of Emission Trends on Future Air Quality

The relationship between emissions and air quality is complex. While some contaminants such as CO, SO_2, and $PM_{2.5}$ are emitted as primary pollutants that have a direct effect on concentrations of these contaminants in the ambient air, other contaminants such as NO_2, O_3, and a portion of the $PM_{2.5}$ in the atmosphere are secondary pollutants that are formed through a complex set of chemical reactions in the atmosphere. For example, O_3 is ultimately formed from the decomposition of NO_2 by sunlight. However, the concentration of O_3 in the atmosphere depends on a complex series of reactions involving both VOCs and NOx. Depending on the ratio of VOC and NOx, control of VOCs may be more effective than the control of NOx in reducing ambient ozone levels. Currently, the VOC/NOx ratio in the LFV is such that VOC control may be more effective in reducing ozone levels.[59] NOx control is relatively ineffective in reducing ozone, but the control of NOx reduces the concentration of other harmful air pollutants, including NO_2 and nitrate particles that contribute to total $PM_{2.5}$ concentrations in ambient air.

Ideally, the relationship between changes in emissions and associated air quality would be determined using photochemical modelling methods to estimate both short-term (1-hour, 8-hour, and 24-hour averages) and long-term (annual average) changes in the concentrations of ozone and $PM_{2.5}$ concentrations which can then be related to either adverse health effects or avoidance of adverse health effects, depending on whether the changes lead to increases or decreases in ambient air concentrations. Conducting a photochemical modeling analysis is a complex, time-consuming, and costly exercise that could not be completed within the budgetary and time constraints available for this review of the AirCare program. Consequently, no new dispersion or photochemical modeling was proposed for this study.

Nevertheless, the potential changes in ambient air quality and the most significant associated health effects can still be reasonably estimated without resorting to photochemical modeling because the major health effects associated with exposure to either ozone or $PM_{2.5}$ are those that result from chronic exposure to average ambient air concentrations of these contaminants rather than acute exposures that are related to the types of episodic events that are typically addressed through photochemical modeling. For example, the valuation of benefits for the U.S. Clear Skies Initiative in 2003 showed that 88-90% of the benefits from changes to ambient air quality were associated with the prevention of premature mortality (U.S. Environmental Protection Agency 2003).[60] Similarly, 98.8% of the monetary damages from the elimination of emissions from coal-fired power plants in Ontario were estimated to be related to reductions in premature

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[59] Personal communications with R. Vingarzan, Pacific and Yukon Region, Environment Canada; D. Steyn and B. Ainslie, Department of Earth and Ocean Sciences, University of British Columbia.

[60] U.S. Environmental Protection Agency 2003. Technical Addendum: Methodologies for the Benefit Analysis of the Clear Skies Act of 2003.

mortality from particulate matter emissions.[61] The analysis of potential health benefits from changes in air quality in the LFV estimated that 85% of the mean mortality events that would be avoided in 2010 and 2020 would be due to chronic exposure to ozone and $PM_{2.5}$ throughout the LFV.

Therefore, the primary driver for estimating the value of any changes in air quality due to the AirCare program in the future will be related to changes in the average ambient air concentrations of $PM_{2.5}$ and ozone rather than to the changes in short-term, acute air quality episodes that are typically evaluated using photochemical models. While it may not be possible to determine the monetary value of all aspects of the changes to health effects without conducting photochemical modeling, the major portion of any benefits that are related to average ambient air concentrations of $PM_{2.5}$ and ozone can be estimated as a proportional relationship between changes in emissions of primary $PM_{2.5}$ and precursors to secondary $PM_{2.5}$ (SO_2, NOx, and VOC) and ozone (NOx and VOC). It is recognized that the relationship may not be linear (e.g., a reduction in SO_2 emissions may reduce the formation of sulphates as a component in $PM_{2.5}$, only to be replaced by an increase in the production of nitrates). As such, there will remain some significant uncertainty about the relative benefits to air quality in the LFV from changes in emissions related to the AirCare program. Nevertheless, there is little alternative to estimating such benefits in the absence of photochemical modelling.

For the review of the AirCare Program, Metro Vancouver provided a source-receptor tool that was developed for the Lower Fraser Valley by RWDI Air Inc.[62] The Reduced Form Source-Receptor Tool (ReFSoRT) is a screening-level spreadsheet tool that uses source-receptor relationships to determine changes in ambient concentrations of common air contaminants resulting from changes in emissions over a specified time period. In essence, the tool compares emissions from all known sources in the LFV for an initial baseline emission scenario to some future changed emission scenario, and uses source-receptor relationships that assume there is a linear relationship between changes in emissions and changes in ambient air quality for both primary and secondary contaminants. According to RWDI Air Inc., the basic linearity of those source-receptor relationships is subsequently adjusted for a number of effects to account for physical and chemical dynamics that influence air quality, including such factors as background concentrations, the importance of individual point sources of emission in key industries, and factors for the comparative contribution of secondary species to total ambient PM concentrations.

ReFSoRT provides estimates of changes in annual average ambient concentrations of NO_2, SO_2, NH_3, VOC, PM_{10} and $PM_{2.5}$, as well as for sulphates, nitrates, and ammonium. For ground-level ozone, the tool estimates changes in daily maximum concentrations during the ozone season. These changes in ambient concentrations are estimated for three regions in the LFV:

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[61] DSS Management Consultants Inc. & RWDI Air Inc. 2005. "Cost Benefit Analysis: Replacing Ontario's Coal-Fired Electricity Generation." Prepared for the Ontario Ministry of Energy.

[62] RWDI Air Inc. 2009. "Developing a Source-Receptor Tool for the Lower Fraser Valley, Victoria and the Okanagan Airsheds." Prepared for Metro Vancouver, Burnaby, BC.

1. The Greater Vancouver Regional District (GVRD);
2. The Fraser Valley Regional District (FVRD);
3. Whatcom County (WA).

According to RWDI Air Inc., ReFSoRT is best suited for estimating changes in ambient air quality that result from emission policies that result in spatially uniform reductions in emissions. In particular, ReFSoRT is considered to be better suited to evaluating changes in emissions from motor vehicles (e.g., due to AirCare), and from changes in other transportation sources such as marine vessels because the changes in emissions from motor vehicles would occur across the entire LFV.

It is important to note that ReFSoRT is a screening-level tool that cannot incorporate all of the complexity of the photochemical reactions in the atmosphere that photochemical models try to replicate. As such, ReFSoRT cannot be expected to have the accuracy of a photochemical model. Furthermore, although RWDI Air Inc. provided an evaluation of the tool by comparing its results to historical ambient monitoring observations and one photochemical model, ReFSoRT has never been independently peer-reviewed, and is not endorsed by Environment Canada.

The original version of the tool that was provided by RWDI to Metro Vancouver included emissions from 1985 to 2025. For the evaluation of the AirCare program, the baseline emissions in the tool were revised to include the period 1990 to 2030 and were updated based on the emission inventory forecasts developed by Metro Vancouver for the 2005 inventory. In the case of the LDV and HDV emissions, the modified baseline emissions with no AirCare program after 2011 were used as the base case scenario, while the modified AirCare program was included in the policy scenario to determine the difference in ambient air quality that would result from the continuation of AirCare in a now, revised program. Because the use of the ReFSoRT model produced some illogical results with respect to predicted changes in ground-level ozone, the potential effects of AirCare on ozone levels were estimated using an alternative method derived by B. Ainslie at the University of British Columbia's Department of Earth and Ocean Sciences.[63]

Because ReFSoRT does not provide estimates for changes in CO concentrations, the benefits of the AirCare program for CO were determined by assuming that the change in total CO emissions for the LFV would result in direct and proportionate changes in short-term (i.e., 1-hour and 8-hour average) maximum concentrations. Since CO is a primary pollutant with a low reactivity level, such an assumption is considered to provide a reasonable estimate of the potential benefits of the AirCare program on reducing CO concentrations.

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[63] Ainslie, B.~D. 2004. "A Photochemical Model Based on a Scaling Analysis of Ozone Photochemistry." Ph.D. thesis, University of British Columbia, Vancouver, B.C., Canada, 311 pp.

With respect to air toxics, Metro Vancouver and Environment Canada issued a report in 2007 on air toxics emissions in the LFV.[64] The report summarized toxic emission estimates for the year 2000, and provided a human health risk assessment for 70-year lifetime cancer risks from 2000 to 2025 based on the existing emission inventory forecasts. Of the 158 substances quantified as being emitted in the LFV, 18 substances accounted for most of the health risk. Four of the five toxic air pollutants discussed below with respect to gasoline-fueled LDVs were included among the top 18 substances that were judged to represent the most health risk in the LFV: acetaldehyde; benzene; 1,3-butadiene; and formaldehyde. For the purposes of the AirCare review, changes in associated concentrations and health risk were estimated in proportion to the year 2000 emission inventory presented in that report.

8.2.1 Potential Effects on Ambient NO_2 Levels – Table 27 lists the expected change in annual average NO_2 concentrations in the three regions of the LFV based on the ReFSoRT spreadsheet calculations. The data indicate that implementation of a modified AirCare program would result in a gradual; but steady reduction in average annual NO_2 concentrations compared with the levels that would exist if the AirCare program were to be terminated in 2011. The improvement in NO_2 levels would range from 0.3 to 0.4 µg/m^3 in 2015, increasing to a reduction of 0.6 to 0.8 µg/m^3 by 2020.

Table 27
Estimated Changes in Average Annual NO_2 Concentrations Due to Modified AirCare Program

Year/ Location	Baseline Annual Average NO_2 Concentration (µg/m^3)	Base Case Annual Average NO_2 Concentration (µg/m^3)	Modified AirCare Program Annual Average NO_2 Concentration (µg/m^3)	Change in Annual Average Concentration (µg/m^3)	% Difference between Base Case and Modified AirCare
2015					
FVRD	20.5	18.7	18.4	-0.3	-1.5%
GVRD	29.2	26.5	26.1	-0.4	-1.6%
2020					
FVRD	20.5	17.9	17.3	-0.6	-3.1%
GVRD	29.2	25.4	24.5	-0.8	-3.3%

8.2.2 Potential Effects on Ambient O_3 Levels – Table 28 lists the expected change in the maximum daily ground-level ozone concentration in the three regions of the LFV as determined by the ReFSoRT spreadsheet. The source-receptor tool suggests that the implementation of the modified AirCare program, which would reduce emissions of the primary ozone precursors NOx and VOC, would result in an increase in maximum daily ground-level ozone throughout the LFV. Specifically, ReFSoRT estimates that

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[64] Levelton Consultants Limited 2007. "Air Toxics Emission Inventory and Health Risk Assessment – Summary Report." Prepared for the Greater Vancouver Regional District and Environment Canada. File No. 404-0423.

Table 28
Estimated Changes in Daily Maximum O_3 Concentrations Due to Modified AirCare Program

Year/ Location	Baseline Daily Maximum O_3 Concentration (ppb)	Base Case Daily Max. O_3 Concentration (ppb)	Modified AirCare Program Daily Max. O_3 Concentration (ppb)	Change in Daily Max. Concentration (ppb)	% Difference between Base Case and Modified AirCare
2015					
FVRD	39.8	41.6	42.1	0.5	1.2%
GVRD	33.9	35.1	35.5	0.4	1.2%
2020					
FVRD	39.8	42.8	43.7	0.9	2.2%
GVRD	33.9	36.1	36.9	0.8	2.2%

implementation of the modified AirCare program would increase ozone concentrations by about 0.5 ppb in the FVRD and Whatcom County by 2015, and that this increase would continue to grow to about 0.9 ppb throughout the LFV by 2020.

The results presented in Table 28 are counterintuitive, and in fact seem illogical. The results are believed to be erroneous, stemming from the fact that ReFSoRT also calculates an increase in ambient VOC concentrations (Table 29) despite the fact that overall VOC levels would decrease between the Base Case and modified AirCare emission scenarios. There is no reason why ReFSoRT should estimate an increase in ambient VOC concentrations for a decrease in VOC emissions.

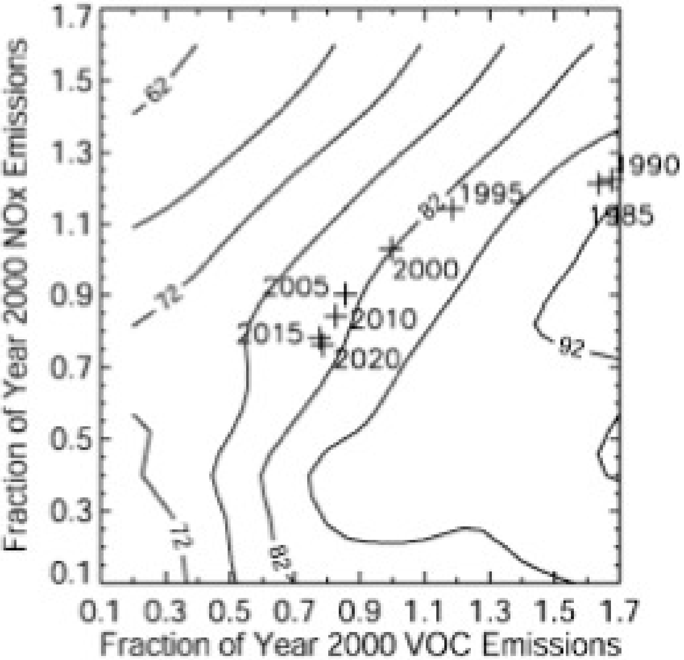
Table 29
Estimated Changes in Annual Average VOC Concentrations Due to Modified AirCare Program

Year/ Location	Baseline Annual Ave. VOC Concentration (μg/m^3)	Base Case Annual Ave. VOC Concentration (μg/m^3)	Modified AirCare Program Annual Ave. VOC Concentration (μg/m^3)	Change in Annual Ave. Concentration (μg/m^3)	% Difference between Base Case and Modified AirCare
2015					
FVRD	30.65	30.18	30.24	0.06	0.2%
GVRD	62.74	61.30	61.48	0.18	0.3%
2020					
FVRD	30.65	30.24	30.29	0.05	0.2%
GVRD	62.74	61.46	61.63	0.16	0.3%

For this reason, the results of the ReFSoRT spreadsheet were discarded and another method was used to estimate the potential benefits of the AirCare program. Figure 37 was provided by B. Ainslie (2004, op. cit.) from his work at the University of British Columbia. As described by Ainslie,[65] the plot in Figure 37 gives region-wide maximum ozone concentrations for the LFV as a function of anthropogenic NOx and VOC emissions. Ainslie used a scaling model for ozone photochemistry along with mesoscale meteorological fields to calculate daily maximum ozone concentrations under Pacific-2001 weather conditions. The scaling model simulations used varying anthropogenic NOx and VOC emissions in 10% steps from 0.1 to 1.7 times the estimated year 2000 emission inventory values. The simulation results were then plotted as the maximum ozone concentration values against the emission fractions. Ainslie also plotted the maximum ozone values one would expect to get using the published emission inventory values for 1985, 1990, 1995, 2005, 2015, and 2020.

Based on Figure 37, Ainslie concluded that, based on this simplified scaling model, NOx and VOC emission reductions between 1985 and 1995 led to reduced peak ozone concentrations, but that further emission reductions since 1995 have not led to ozone decreases. This conclusion is indicated by the fact that the maximum predicted ozone values for 1995-2020 seem to be tracking along the 80 ppb isopleth. Ainslie suggests that the region is VOC-limited, and that continued reductions in NOx emissions will have little impact on peak ozone during summertime ozone events.

Figure 37
Ozone Isopleths Through Various Emissions Inventories
for the August 2001 Episode



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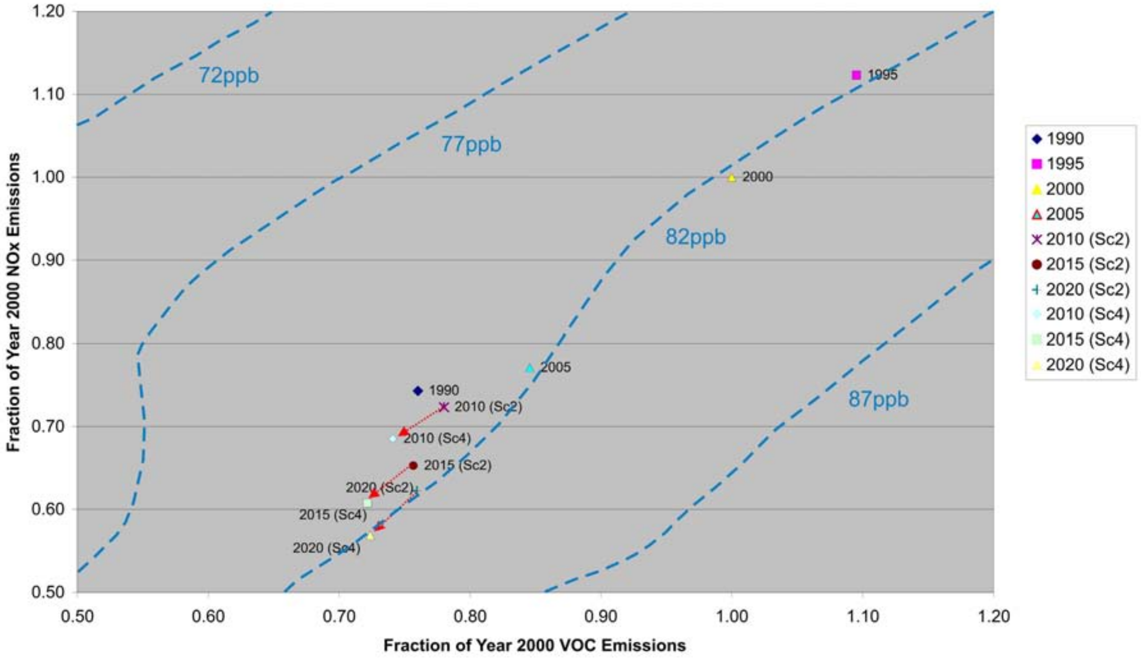
[65] Personal communication, February 5, 2009.

Ainslie notes that these results have not yet been replicated through photochemical modelling, but that such verification is currently in progress at the University of British Columbia. It is worth noting that R. Vingarzan at Environment Canada, Pacific and Yukon Region, has independently come to the same conclusion that the LFV airshed is VOC-limited, based on soon-to-be published analyses of trends in ozone monitoring data.[66]

Figure 38 reproduces the isopleths calculated by Ainslie, with the ratio of the NOx and VOC emission inventories for the period 1990-2020 used in the current review of the AirCare program superimposed on the isopleths. For the period 2010-2020, the difference in the effect on ozone concentrations due to changes in emissions between the No I/M Base Case (Scenario 2) and the modified AirCare program (Scenario 4) are indicated by the shift in the NOx and VOC ratios along the two axes (red arrows). The figure suggests that the net effect of the modified AirCare program would be to continue to track parallel to the 80 ppb isopleths, resulting in no net change in ambient ozone levels in the LFV. In fact, the overall net effect of all of the anticipated changes in the LFV emission inventory to 2020 suggests a gradual increase in ozone concentrations by about 1 ppb.

Figure 38
Ozone Isopleths Through Various Emission Inventories
for the August 2001 Episode (Scenario 2 - Sc2; Scenario 4 - Sc4)



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[66] Personal communication, February 3, 2009.

Using Figure 38, it would be possible to estimate a maximum potential benefit for the AirCare program of about 0.5 ppb in the daily maximum 1-hour average ozone concentration due to reductions in VOC emissions alone between the modified baseline emission estimates (Scenario 2) and the modified AirCare emission estimates (Scenario 4), provided that NOx emissions were kept constant. Although not shown on Figure 38, the difference in AirCare benefits between the baseline VOC emissions with no I/M program (Scenario 1) and the current AirCare program (Scenario 3) is only about 40% of the VOC reduction between Scenarios 2 and 4. Therefore, it might be estimated that the benefits of the current AirCare program would amount to only about a 0.2 ppb difference in daily maximum ozone concentrations (once again assuming that NOx emissions are kept constant).

It is also true that reductions in CO emissions may provide some minor benefit to reducing ambient ozone concentrations. Although the reactivity of CO is low compared to VOC compounds, CO does factor into the photochemical reactions that produce ground-level ozone. Nevertheless, if CO emissions were a significant factor in determining ozone levels in the LFV, the large reductions in CO emissions that have occurred since 1990 should have resulted in a trend toward lower ambient ozone levels. Furthermore, any such benefits could be determined only through use of a photochemical model, which is beyond the scope of this assessment.

Therefore, for the purposes of this review of the AirCare program, the maximum potential benefit of the reduction in VOC emissions due to AirCare would be a reduction of about 0.5 ppb in maximum daily ozone concentrations across the LFV, but it is equally likely, perhaps even more likely, that there would be no net benefit to ozone levels.

It should also be noted that a change in O_3 concentrations of 0.5 ppb is within the uncertainty bounds for any photochemical model. Therefore, the use of a photochemical model to estimate the potential benefits of the AirCare program instead of the ReFSoRT spreadsheet would not necessarily produce a more definitive estimate of the potential benefits of the AirCare program.

8.2.3 Potential Effects on Ambient $PM_{2.5}$ Levels – Since the AirCare program has no effect on changing the emissions of primary particulate matter from light-duty vehicles, the ReFSoRT spreadsheet estimates that there would be no change in ambient levels of $PM_{2.5}$ from 2010 to 2020. AirCare could, however, affect the formation of secondary particulate matter through reductions in the emission of NOx and VOC. Since ReFSoRT does not provide any calculation of secondary particulate matter benefits, any such benefits would have to be determined by alternative means.

Photochemical modeling of secondary particulate matter in the LFV by Environment Canada using the CMAQ model has suggested that the most direct way to reduce ammonium nitrate formation would be to reduce ammonia emissions from agricultural sources in the LFV. Small reductions in ammonia emissions would be expected to produce linearly proportionate reductions in secondary ammonium nitrate. However, Environment Canada is currently unable to explain why the past changes in emission reductions in the LFV have not resulted in the types of reductions in secondary particulate matter that the CMAQ model predicts. At present, Environment Canada considers that there is no credible way to determine the impacts of NOx emission reductions on changes in secondary (nitrate) particulate matter in the LFV except through the use of a photochemical model.[67] Since the use of a photochemical model was beyond the scope of work for the AirCare program review, no potential benefits from the reduction in NOx emissions were estimated.

With respect to secondary organic aerosols (SOA) formed from the photochemical reaction of some VOC, Environment Canada provided some simple conversion factors that could be used to estimate the degree of which the reduced VOC emissions could be expected to reduce the formation of SOA in the LFV.[68] These factors are currently being used to estimate SOA formation in episodic air quality modelling using the unified regional air quality modeling system (AURAMS). The conversion factors provide an estimate of the fraction of the emitted VOC that could be converted to SOA during a brief air pollution episode and have been used to estimate SOA formation in the LFV.[69]

The U.S. EPA SPECIATE database was used to define the speciated VOC emissions from LDV exhaust and evaporative emissions. These profiles (Profile No. 1203 for exhaust; Profile 1204 for evaporative emissions) were applied to the estimated VOC emissions for the four emission scenarios used in the AirCare review to calculate the total amount of each compound that would be emitted in each scenario. The differences in emissions between Base case No I/M Scenarios 1 and 2 and between the current AirCare program (Scenario 3) and the modified AirCare program (Scenario 4), respectively, were used to estimate the difference in the amount of each compound that would be emitted with and without the AirCare program. The SOA conversion factors provided by Environment Canada were then applied to those compounds that have been identified as contributing to SOA formation in experimental chamber studies.[70,71] Table 30 lists the VOC species used in the calculations, the fraction of total VOC attributed to each species in LDV exhaust and evaporative emissions, and the SOA conversion factors applied to each species.

Table 31 lists the VOC emission estimates for the four emission scenarios used to estimate the total amount of SOA that could be formed from the application of the SOA conversion factors to the LDV emissions. It should be noted, however, that the application of these conversion factors to total annual VOC emissions may overestimate the amount of SOA that could be formed for each scenario because the rate at which SOA is formed depends on both temperature and relative humidity. Consequently, the conversion rates listed in Table 30, which are applicable to episodic modeling scenarios during the summer months, may not be applicable for the colder months of the year. In

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[67] C. di Cenzo, Environment Canada, Pacific and Yukon Region, personal communication, May 7, 2010.

[68] M. Moran and C. Stroud, Environment Canada, Ontario, personal communication, May 19, 2010.

[69] Stroud, C.A., G. Morneau, P.A. Makar, M.D. Moran, W. Gong, B. Pabla, J. Zhang, V.S. Bouchet, D. Fox, S. Venkatesh, D. Wang and T. Dann 2008. "OH-reactivity of volatile organic compounds at urban and rural sites across Canada: Evaluation of air quality model predictions using speciated VOC measurements." Atmospheric Environment 42:7746-7756.

[70] Grosjean D. and J.H. Seinfeld 1989. "Parameterization of the formation potential of secondary organic aerosols." Atmospheric Environment 23(8):1733-1747.

[71] Dusek, U. 2000. "Secondary Organic Aerosol – Formation Mechanisms and Source Contributions in Europe." International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, IR-00-066.

Table 30
Exhaust and Evaporative VOC Species and Associated SOA Conversion Factors

CAS	Exhaust VOC Profile #1203		Exhaust VOC Profile #1204		SOA Conversion Factor (%)
	Percent by weight	**Species**	**Percent by weight**	**Species**	
526-73-8	0.81	1,2,3-trimethylbenzene			4.8
95-63-6	2.9	1,2,4-trimethylbenzene (1,3,4-trimethylbenzene)	1.21	1,2,4-trimethylbenzene (1,3,4-trimethylbenzene)	4.8
108-67-8	2.21	1,3,5-trimethylbenzene	0.71	1,3,5-trimethylbenzene	4.8
100-41-4	0.88	Ethylbenzene	0.53	Ethylbenzene	13.0
124-18-5	0.2	N-decane	0.2	N-decane	3.8
142-82-5	0.53	N-heptane	0.52	N-heptane	3.8
111-84-2	0.25	N-nonane	0.12	N-nonane	3.8
111-65-9	0.3	N-octane	0.24	N-octane	3.8
1120-21-4	0.6	N-undecane	0.09	N-undecane	3.8
95-47-6	1.76	O-xylene	0.87	O-xylene	4.8
106-42-3	2.87	P-xylene	2.11	P-xylene	4.8
108-88-3	5.72	Toluene	8.51	Toluene	13.0
N/A	2.65	C10 Aromatic	0.63	C10 Aromatic	4.8

Table 31
VOC Emissions Estimates

I/M Case	Type of Emission	VOC Emissions (tonnes/year)		
		2010	**2015**	**2020**
Scenario 1 None, MOBILE No I/M Baseline	Exhaust	6764	4836	4403
	Evaporative	6236	4059	2762
Scenario 2 None, Modified No I/M Baseline	Exhaust	7673	6112	6008
	Evaporative	6236	4059	2762
Scenario 3 Current Program	Exhaust	5239	3402	2796
	Evaporative	6108	3910	2581
Scenario 4 Modified Program	Exhaust	5162	3328	2708
	Evaporative	3821	2419	1581

fact, only about 41% of total annual VOC emissions would occur in the five warm summer months of May through September. However, Makar et al.[72] reported that a larger proportion of the anthropogenic VOC emissions may be converted to SOA in winter than in summer, such that the application of the SOA conversion factors over the entire year may not be unreasonable. On the other hand, Strader et al.[73] used three different methods to predict SOA concentrations in the San Joaquin Valley of California in winter. The authors reported that most of the organic carbon aerosol present in wintertime particulate matter was of primary origin, but that low mixing heights in winter could lead to the accumulation of SOA precursors and lead to an acceleration of SOA formation. The presence of clouds and fog may slow down the production of SOA by a factor of two to three compared to maximum formation rates.

According to C. Stroud and M. Moran of Environment Canada[74], SOA yields would be higher at lower temperatures. The SOA yields are SOA formed per amount of precursor VOC reacted. At lower temperatures in the winter, a small decrease in hydroxyl (OH) radicals due to less sunlight and water vapor will decrease the conversion rate of anthropogenic VOCs, however the higher yield of SOA at lower temperatures would likely more than compensate for the decrease in OH to needed to drive the chemical reactions. Therefore, it is possible that the winter SOA concentrations from LDV VOC emissions could be similar to those in the May-September period. There is at present insufficient information available to determine what the actual SOA formation rates would be in the LFV in winter. For the purposes of this assessment, a range between range between full conversion rates as listed in Table 30 and lower conversion rates at one-third those listed rates represents the degree of uncertainty that may be considered for the evaluation of the AirCare program benefits.

Table 32 lists the estimated SOA formation for each of the four emission scenarios and the differences between Scenarios 1 and 3 and Scenarios 2 and 4. If it is assumed that SOA formation rates during the months of November-April are 2-3 times lower than they are in the period May-September, then the total SOA formation would be 60-70% of the values listed in Table 32 under the columns Jan-Dec.

For the purposes of this assessment, health effects benefits and monetary valuation of the AirCare program has been calculated for both the case where the SOA conversion factors apply throughout the entire year and for the case where they only apply for the period May-September. A third option may also be considered in which the conversion factors in Table 30 apply for May-September, and a lower rate of one-third applies to the rest of the year, such that total annual SOA formation equals 60% of the annual levels (Jan-Dec) listed in Table 32.

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[72] Makar, P.A., M.D. Moran, M.T Scholtz and A. W. Taylor 2001. “Application of the Canadian Emissions Processing System, Version 1.1, to Estimate Organic Aerosol Composition for North America.” 10th International Emission Inventory Conference - “One Atmosphere, One Inventory, Many Challenges,” May 1-3, 2001.

[73] Strader, R., F. Lurmann and S. Pandis 1999. “Evaluation of secondary organic aerosol formation in winter.” Atmospheric Environment 33(29):4849-4863.

[74] Personal communication, 2 June 2010.

Table 32
Estimated SOA Formation for LDV Emissions

Emission Scenario		Estimated SOA Formation (tonnes)					
		2010		2015		2020	
		Jan-Dec	May-Sep	Jan-Dec	May-Sep	Jan-Dec	May-Sep
Sc1	Exhaust	103.9	39.8	74.3	28.5	67.7	26.0
	Evaporative	89.9	40.2	58.5	26.1	39.8	17.7
	Total	**193.8**	**80.1**	**132.8**	**54.6**	**107.5**	**43.8**
Sc2	Exhaust	117.9	45.2	93.9	36.0	92.3	35.5
	Evaporative	89.9	40.2	58.5	26.1	39.8	17.7
	Total	**207.8**	**85.4**	**152.4**	**62.1**	**132.1**	**53.2**
Sc3	Exhaust	80.5	30.8	52.3	20.0	43.0	16.5
	Evaporative	88.1	39.2	56.4	25.0	37.2	16.3
	Total	**168.6**	**70.0**	**108.6**	**45.0**	**80.2**	**32.9**
Sc4	Exhaust	79.3	30.3	51.1	19.6	41.6	16.0
	Evaporative	55.1	25.4	34.9	15.9	22.8	10.3
	Total	**134.4**	**55.7**	**86.0**	**35.5**	**64.4**	**26.3**
Potential SOA reduction (Sc1-Sc3)		**25.3**	**10.0**	**24.2**	**9.6**	**27.3**	**10.9**
Potential SOA Reduction (Sc1-Sc4)		**73.4**	**29.7**	**66.4**	**26.6**	**67.7**	**27.0**

Table 33 lists the potential benefits of these reductions in SOA formation in terms of a percentage decrease relative to total primary particulate matter emissions in the LFV.

Table 33
Potential SOA Reduction Relative to Total Primary PM Emissions in the LFV

Emission Scenario	SOA Reduction as Equivalent % change in Primary PM Emissions					
	2010		2015		2020	
	Jan-Dec	May-Sep	Jan-Dec	May-Sep	Jan-Dec	May-Sep
Potential SOA reduction (Sc1-Sc3)	0.37	0.15	0.35	0.14	0.38	0.15
Potential SOA Reduction (Sc1-Sc4)	1.08	0.44	0.95	0.38	0.95	0.38

Table 34 lists the potential effects of the current and modified AirCare programs on ambient SOA $PM_{2.5}$ concentrations in the LFV as determined using the ReFSoRT spreadsheet, assuming that a reduction in SOA is equivalent to a similar reduction in primary particulate matter emissions from LDV. Note that these differences are based on the application of the SOA conversion factors during the entire year. If it is assumed that the conversion factors are applicable only during the months of May-September, then the potential benefits would be reduced to 41% of those listed in Table 34.

Table 34
Estimated Changes in Annual Average SOA $PM_{2.5}$ Concentrations Due to Modified AirCare Program

	Total $PM_{2.5}$ Concentration (μg/m^3)	Total $PM_{2.5}$ Concentration (μg/m^3)	Change in Concentration (μg/m3)
2010	**Scenario 2**	**Scenario 4**	
FVRD	4.88	4.88	0.0
GVRD	5.55	5.55	0.0
2015			
FVRD	4.98	4.95	0.03
GVRD	5.69	5.64	0.05
2020			
FVRD	5.08	5.05	0.03
GVRD	5.83	5.78	0.05
2010	**Scenario 1**	**Scenario 3**	
FVRD	4.88	4.88	0.0
GVRD	5.55	5.55	0.0
2015			
FVRD	4.98	4.97	0.01
GVRD	5.69	5.66	0.03
2020			
FVRD	5.08	5.08	0.01
GVRD	5.83	5.80	0.03

8.2.4 Potential Effects on Ambient CO Levels – Since the ReFSoRT spreadsheet does not consider CO, the potential benefits of the AirCare program on ambient CO concentrations in the LFV were estimated as a direct proportional change to total CO emissions from all sources in the LFV. The maximum 1-hour average CO concentrations at NAPS stations during the period 2004-2006 were used to calculate a 3-year average as a baseline. The percentage change in emissions between the total CO emissions in the LFV for the No I/M baseline LDV and HDV emissions (Scenarios 1 and 2) and the current (Scenario 3) and modified (Scenraio 4) AirCare programs LDV and HDV emissions was applied to the baseline ambient CO concentrations. The results are presented in Table 35.

Table 35
Estimated Changes in Annual Average CO Concentrations Due to Modified AirCare Program

I/M Scenario		2010	2015	2020
Scenario 1 None, MOBILE No I/M Baseline	% Change in Total LFV CO Emissions from 2010	6.14%	11.3%	9.02%
	Expected 1-hour Average CO Concentrations (µg/m3)	6278	5951	6086
Scenario 2 None, Modified No I/M Baseline	% Change in Total LFV CO Emissions from 2010	1.94%	5.31%	1.77%
	Expected 1-hour Average CO Concentrations (µg/m3)	5803	6334	6570
Scenario 3 Current Program	% Change in Total LFV CO Emissions from 2010	13.24%	17.59%	16.28%
	Expected 1-hour Average CO Concentrations (µg/m3)	5803	5512	5600
Scenario 4 Modified Program	% Change in Total LFV CO Emissions from 2010	13.56%	17.89%	16.63%
	Expected 1-hour Average CO Concentrations (µg/m3)	2741	2604	2644

Table 35 indicates that total CO emissions in the LFV would be reduced by about 13% in 2010 by the implementation of either the current or the modified AirCare programs, and that the reduction would reach 16% by 2020 compared with the No I/M baseline emissions. The change in ambient concentrations is presumed to be proportionate in each time period across the entire LFV.

8.3 Potential Health and Economic Benefits of AirCare

The potential benefits from emission reductions from both the continuation of the current AirCare program or the implementation of a modified AirCare program were evaluated using the Air Quality Benefits Assessment Tool (AQBAT). AQBAT is a computer simulation tool designed to estimate the human health and welfare benefits or damages associated with changes in ambient air quality. AQBAT was developed at the Biostatistics and Epidemiology Division, Health Canada by S. Judek and D. Steib. The most recent update of AQBAT that was used for the assessment of the AirCare program was released in Spring 2010.

AQBAT allows for the definition of a wide range of specific scenario models from combining and linking of pollutants, health endpoints, geographic areas, and scenario years. AQBAT contains historical and projected population data, and accesses preset data files of historical and hypothetical pollutant concentrations along with data files of baseline health endpoint rates. The tool performs Monte Carlo simulations to provide a range of possible health effects outcomes and associated economic valuations for each scenario, ranged around a central value that provides the best estimate of the simulation.

The current pollutants in AQBAT are four gas and two particle type pollutants, including CO, NO_2, O_3, SO_2, PM_{10}, and $PM_{2.5}$, with 1-hour maximum and 24-hour average metrics for the gases and 24-hour average metrics for PM_{10} and $PM_{2.5}$. There is also an 8-hour maximum metric for ozone. The summary statistics derived for the pollutants generally apply to all months of the year. In addition, however, there are seasonal distinctions for ozone because O_3 concentrations vary according to the time of year much more than the other pollutants.

AQBAT can be used to forecast health damages of air pollution at the census division level, using available information on population age and gender from Statistics Canada for each census division. AQBAT estimates the number of incidences for the health outcomes listed below.

Acute Exposure Mortality
Acute Respiratory Symptom Days
Adult Chronic Bronchitis Cases
Asthma Symptom Days
Cardiac Emergency Room Visits
Cardiac Hospital Admissions
Child Acute Bronchitis Episodes
Chronic Exposure Mortality
Elderly Cardiac Hospital Admissions
Minor Restricted Activity Days
Respiratory Emergency Room Visits
Respiratory Hospital Admissions and
Restricted Activity Days

Each of these is either a short-term exposure or acute health endpoint, or a long-term exposure or chronic health endpoint. Each of these endpoints also corresponds to a certain proportion of a specific population age group.

As defined in AQBAT, monetary valuation reflects the value to society of a change in the frequency of the health outcome in question. The aggregate monetary valuation of health benefits can be compared to the costs of attaining improved air quality to determine whether an intervention results in a net benefit to society. As in the case of concentration response functions (CRF) used to estimate health outcomes, endpoint valuation estimates are associated with uncertainty. AQBAT provides options to select a distribution form (normal, triangular, or 3-point discrete) and inputs the corresponding parameter values in AQBAT to specify the possible values and their likelihood (Endpoint Valuation – EPV). AQBAT multiplies a health endpoint count by a sampled dollar valuation per count to get a sample of the total $ valuation of the health endpoint for a pollutant, geographic area and scenario year. As with CRFs, EPVs can be geographic area-specific; multiple EPVs for the same endpoint can be included in a scenario model to reflect this.

The economic value of these effects are estimated in 2004 dollar values in AQBAT, and were prorated to account for inflation to 2010 using the Consumer Price Index as defined by R. Sahr,[75] but future monetary costs and benefits were not adjusted to account for inflation.

In the discussion of monetary valuations of the AirCare program, it should be noted that the valuation points do not all sum up to be equal to "all endpoints." Instead, AQBAT calculates a netting of endpoints that avoids double counting of some endpoints. This is necessary because in some cases one health endpoint may have started out as another endpoint. For example, Respiratory Hospital Admissions (RHAs) are subtracted from Respiratory Emergency Room Visits (RERVs), under the assumption that RHAs started out as RERVs. In the current version of AQBAT, the netted endpoints are, by default:

- Acute Respiratory Symptom Days
  - Minor Restricted Activity Days, Restricted Activity Days
- Cardiac Emergency Room Visits
  - Cardiac Hospital Admissions, Elderly Cardiac Hospital Admissions
- Respiratory Emergency Room Visits
  - Respiratory Hospital Admissions

In the current version of AQBAT, the following are the grouped endpoints:

- Acute Exposure Mortality + Chronic Exposure Mortality
- Cardiac Hospital Admissions + Elderly Cardiac Hospital Admissions + Respiratory Hospital Admissions
- Cardiac Emergency Room Visits + Respiratory Emergency Room Visits.

In the following discussion, the potential health outcomes and economic valuations are summarized separately for the GVRD and FVRD. However, since AQBAT does not include areas outside the Canadian borders, any health outcomes or benefits accruing to Whatcom County from the implementation of the AirCare program are not considered. Results are presented for CO, NO_2, O_3, and $PM_{2.5}$. The results are presented for a central value, as well as the 25th and 75th percentile values in the probability distribution of outcomes and valuations, to provide a measure of the spread in uncertainty associated with such assessments.

8.3.1 Potential Health Outcomes and Benefits – Table 36 lists the potential health outcomes determined using AQBAT for the reductions in annual average NO_2 concentrations in Metro Vancouver (GVRD), the Fraser Valley Regional District (FVRD), and the Canadian portion of the LFV (CDN LFV), as presented in Table 27. AQBAT provides results for only one health outcome related to NO_2 reductions, namely acute exposure mortality. The central estimate results suggest that there could potentially

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[75] Sahr, R. 2008. Consumer Price Index (CPI), Political Science Department, Oregon State University, Cornvallis, OR. http://oregonstate.edu/cla/polisci/faculty/sahr-robert

Table 36
Estimated AirCare Benefits from Reductions in Acute Exposure Mortality Due to NO_2 Reductions in the Canadian LFV

Time Period	Number of Incidences		
	FVRD	**GVRD**	**CDN LFV**
2011-2015	**Current AirCare Program**		
25th percentile	0.5	4.1	**4.7**
Central estimate	0.7	5.3	**6.0**
75th percentile	0.9	6.5	**7.3**
2016-2020			
25th percentile	1.0	12.0	**12.9**
Central estimate	1.2	15.4	**16.7**
75th percentile	1.5	18.9	**20.4**
2011-2020			
25th percentile	1.5	16.1	**17.6**
Central estimate	1.9	20.7	**22.7**
75th percentile	2.4	25.4	**27.8**
2011-2015	**Modified AirCare Program**		
25th percentile	1.6	16.5	**18.1**
Central estimate	2.1	21.2	**23.3**
75th percentile	2.6	26.0	**28.5**
2016-2020			
25th percentile	4.7	52.4	**57.2**
Central estimate	6.1	67.6	**73.7**
75th percentile	7.5	82.8	**90.3**
2011-2020			
25th percentile	6.3	68.9	**75.2**
Central estimate	8.2	88.8	**97.0**
75th percentile	10.0	108.8	**118.8**

be 23 fewer premature deaths in the Canadian portion of the LFV for the period 2011-2020 from the continuation of the current AirCare program, and 97 fewer premature deaths over the period 2011-2020 from the implementation of the modified AirCare program. Therefore, the modified AirCare program would be over four times more effective at reducing incidences of acute exposure mortality related to LDV NOx emissions than the continuation of the current AirCare program would provide.

As discussed below, a similar calculation of potential benefits from the effects of AirCare on the daily maximum ambient ozone concentration was not possible to compute using the ReFSoRT spreadsheet. Instead, a hypothetical maximum decrease of 0.2 ppb (assumed to apply year-round) for the current AirCare program and 0.5 ppb for the implementation of a modified AirCare program were estimated based on Figure 38, by ignoring the simultaneous reduction in NOx emissions due to AirCare. The potential health outcome benefits due to such a reduction are presented in Table 37. (Note that morbidity outcomes for O_3 exposure are not possible as these are related to episodic exposures during the warm season [May to September], and such an assessment would entail the use of a photochemical model to estimate changes in ground-level O_3 concentrations.)

Table 37 indicates that a 0.2 ppb reduction in daily maximum 1-hour average ground-level ozone concentration across the entire Canadian portion of the LFV under the current AirCare program could result in 38 fewer premature deaths in the period 2011-2020, while a 0.5 ppb reduction for the modified AirCare program would result in 94 fewer premature deaths. As discussed below, however, these benefits may not actually be realised because, as depicted in Figure 38, the AirCare program may not provide any actual benefits in terms of reduced ambient ozone concentrations in the LFV.

Table 37
Estimated AirCare Benefits from Reductions in Acute Exposure Mortality Due to O_3 Reductions in the Canadian LFV

	Number of Incidences		
Time Period	**FVRD**	**GVRD**	**CDN LFV**
2011-2015	**Current AirCare Program**		
25th percentile	1.4	10.6	**12.0**
Central estimate	1.6	11.9	**13.5**
75th percentile	1.7	13.2	**14.9**
2016-2020			
25th percentile	2.5	18.9	**21.4**
Central estimate	2.8	21.3	**24.1**
75th percentile	3.1	23.6	**26.7**
2011-2020			
25th percentile	3.9	29.5	**33.4**
Central estimate	4.4	33.2	**37.5**
75th percentile	4.8	36.8	**41.6**
2011-2015	**Modified AirCare Program**		
25th percentile	3.5	26.5	**30.0**
Central estimate	3.9	29.7	**33.7**
75th percentile	4.3	33.0	**37.3**
2016-2020			
25th percentile	6.2	47.3	**53.6**
Central estimate	7.0	53.2	**60.2**
75th percentile	7.8	59.0	**66.7**
2011-2020			
25th percentile	9.7	73.8	**83.6**
Central estimate	10.9	82.9	**93.8**
75th percentile	12.1	92.0	**104.1**

As discussed below, the ReFSoRT spreadsheet estimated that there would be no change in ambient $PM_{2.5}$ concentrations in the LFV over the period 2011-2020 for primary particulate matter emissions. Furthermore, there is no credible way to estimate the potential benefits of secondary particulate matter (nitrate) reductions due to AirCare reductions in NOx emissions short of running a photochemical model. Therefore, the only potential benefits of AirCare with respect to secondary particulate matter are those related to secondary organic aerosol associated with reductions in LDV VOC emissions from the current and modified AirCare programs.

The potential health benefits arising from a decrease in $PM_{2.5}$ concentrations due to SOA reductions are summarized in Tables 38 to 41 for the current and modified AirCare programs. Table 38 lists the potential health benefits for the continuation of the current AirCare program assuming that the SOA conversion factors can be applied over the course of the entire year (January-December), while Table 39 lists the health benefits if the SOA conversion factors are applied only for the warm season (May-September). Similarly, Table 40 lists the potential health benefits for the implementation of the modified AirCare program assuming that the SOA conversion factors can be applied over the course of the entire year (January-December), while Table 41 lists the health benefits if the SOA conversion factors are applied only for the warm season (May-September).

Table 38
Estimated Health Outcome Due to SOA Decreases (January-December) From the Continuation of the Current AirCare Program in the Canadian LFV

Health Outcomes	**Number of Incidences**								
	25th Percentile			**Central Estimate**			**75th Percentile**		
	2011-2015	**2016-2020**	**2011-2020**	**2011-2015**	**2016-2020**	**2011-2020**	**2011-2015**	**2016-2020**	**2011-2020**
	FVRD								
Acute Respiratory Symptom Days	320.9	214.0	**534.9**	810.7	540.5	**1351.1**	1287.9	858.6	**2146.5**
Adult Chronic Bronchitis Cases	0.3	0.2	**0.5**	0.5	0.3	**0.8**	0.7	0.4	**1.1**
Asthma Symptom Days	13.7	9.1	**22.8**	24.2	16.2	**40.4**	34.8	23.2	**58.0**
Cardiac Emergency Room Visits	0.0	0.0	**0.0**	0.0	0.0	**0.0**	0.0	0.0	**0.0**
Cardiac Hospital Admissions	0.0	0.0	**0.1**	0.0	0.0	**0.1**	0.1	0.0	**0.1**
Child Acute Bronchitis Episodes	2.1	1.4	**3.6**	3.7	2.4	**6.1**	5.2	3.5	**8.7**
Respiratory Emergency Room Visits	0.2	0.1	**0.3**	0.2	0.1	**0.3**	0.2	0.1	**0.4**
Respiratory Hospital Admissions	0.0	0.0	**0.1**	0.0	0.0	**0.1**	0.1	0.0	**0.1**
Restricted Activity Days	470.5	313.7	**784.1**	548.1	365.4	**913.5**	625.7	417.1	**1042.8**
Chronic Exposure Mortality	0.5	0.4	**0.9**	0.6	0.4	**1.1**	0.7	0.5	**1.2**
	GVRD								
Acute Respiratory Symptom Days	7180.8	12253.4	**19434.2**	19539.0	33543.7	**53082.7**	31535.6	54197.2	**85732.8**
Adult Chronic Bronchitis Cases	8.6	14.9	**23.4**	13.1	22.8	**35.9**	17.7	30.7	**48.4**
Asthma Symptom Days	343.1	590.9	**934.0**	608.5	1047.9	**1656.4**	873.8	1504.8	**2378.6**
Cardiac Emergency Room Visits	0.1	0.1	**0.1**	0.3	0.6	**0.9**	0.6	1.0	**1.6**
Cardiac Hospital Admissions	0.9	1.5	**2.4**	1.0	1.8	**2.9**	1.2	2.1	**3.3**
Child Acute Bronchitis Episodes	44.2	74.9	**119.1**	75.7	128.3	**204.0**	107.2	181.7	**288.9**
Respiratory Emergency Room Visits	3.6	6.4	**9.9**	4.2	7.5	**11.7**	4.8	8.6	**13.4**
Respiratory Hospital Admissions	0.9	1.6	**2.5**	1.0	1.9	**2.9**	1.2	2.1	**3.2**
Restricted Activity Days	12508.8	21628.2	**34137.0**	14572.5	25196.6	**39769.2**	16635.2	28763.0	**45398.2**
Chronic Exposure Mortality	12.2	21.9	**34.1**	14.4	25.7	**40.1**	16.5	29.5	**46.1**
CDN LFV									
Acute Respiratory Symptom Days	7501.7	12467.4	**19969.1**	20349.7	34084.2	**54433.9**	32823.5	55055.9	**87879.4**
Adult Chronic Bronchitis Cases	8.9	15.1	**24.0**	13.6	23.1	**36.8**	18.4	31.2	**49.5**
Asthma Symptom Days	356.8	600.0	**956.8**	632.8	1064.1	**1696.8**	908.6	1528.0	**2436.6**
Cardiac Emergency Room Visits	0.1	0.1	**0.1**	0.3	0.6	**0.9**	0.6	1.1	**1.7**
Cardiac Hospital Admissions	0.9	1.6	**2.5**	1.1	1.9	**2.9**	1.2	2.2	**3.4**
Child Acute Bronchitis Episodes	46.4	76.4	**122.7**	79.4	130.8	**210.2**	112.4	185.2	**297.6**
Respiratory Emergency Room Visits	3.7	6.5	**10.2**	4.4	7.6	**12.0**	5.0	8.8	**13.8**
Respiratory Hospital Admissions	1.0	1.7	**2.6**	1.1	1.9	**3.0**	1.2	2.1	**3.3**
Restricted Activity Days	12979.2	21941.9	**34921.1**	15120.6	25562.0	**40682.7**	17260.9	29180.1	**46441.0**
Chronic Exposure Mortality	12.8	22.2	**35.0**	15.0	26.1	**41.1**	17.3	30.0	**47.3**

Table 39
Estimated Health Outcome Due to SOA Decreases (May-September) From the Continuation of the Current AirCare Program in the Canadian LFV

Health Outcomes	Number of Incidences								
	25th Percentile			Central Estimate			75th Percentile		
	2011-2015	2016-2020	2011-2020	2011-2015	2016-2020	2011-2020	2011-2015	2016-2020	2011-2020
	FVRD								
Acute Respiratory Symptom Days	131.6	87.7	219.3	332.4	221.6	554.0	528.0	352.0	880.1
Adult Chronic Bronchitis Cases	0.1	0.1	0.2	0.2	0.1	0.3	0.3	0.2	0.5
Asthma Symptom Days	5.6	3.7	9.3	9.9	6.6	16.6	14.3	9.5	23.8
Cardiac Emergency Room Visits	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cardiac Hospital Admissions	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Child Acute Bronchitis Episodes	0.9	0.6	1.5	1.5	1.0	2.5	2.1	1.4	3.6
Respiratory Emergency Room Visits	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Respiratory Hospital Admissions	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Restricted Activity Days	192.9	128.6	321.5	224.7	149.8	374.5	256.5	171.0	427.6
Chronic Exposure Mortality	0.2	0.1	0.4	0.3	0.2	0.4	0.3	0.2	0.5
	GVRD								
Acute Respiratory Symptom Days	2944.1	5023.9	7968.0	8011.0	13752.9	21763.9	12929.6	22220.9	35150.5
Adult Chronic Bronchitis Cases	3.5	6.1	9.6	5.4	9.4	14.7	7.2	12.6	19.8
Asthma Symptom Days	140.7	242.3	382.9	249.5	429.6	679.1	358.3	616.9	975.2
Cardiac Emergency Room Visits	0.0	0.0	0.1	0.1	0.2	0.4	0.2	0.4	0.7
Cardiac Hospital Admissions	0.4	0.6	1.0	0.4	0.8	1.2	0.5	0.9	1.4
Child Acute Bronchitis Episodes	18.1	30.7	48.8	31.0	52.6	83.7	44.0	74.5	118.5
Respiratory Emergency Room Visits	1.5	2.6	4.1	1.7	3.1	4.8	2.0	3.5	5.5
Respiratory Hospital Admissions	0.4	0.7	1.0	0.4	0.8	1.2	0.5	0.8	1.3
Restricted Activity Days	5128.6	8867.6	13996.2	5974.7	10330.6	16305.4	6820.4	11792.8	18613.2
Chronic Exposure Mortality	5.0	9.0	14.0	5.9	10.5	16.4	6.8	12.1	18.9
	CDN LFV								
Acute Respiratory Symptom Days	3075.7	5111.6	**8187.3**	8343.4	13974.5	**22317.9**	13457.6	22572.9	**36030.5**
Adult Chronic Bronchitis Cases	3.6	6.2	**9.8**	5.6	9.5	**15.1**	7.5	12.8	**20.3**
Asthma Symptom Days	146.3	246.0	**392.3**	259.4	436.3	**695.7**	372.5	626.5	**999.0**
Cardiac Emergency Room Visits	0.0	0.0	**0.1**	0.1	0.2	**0.4**	0.2	0.4	**0.7**
Cardiac Hospital Admissions	0.4	0.6	**1.0**	0.4	0.8	**1.2**	0.5	0.9	**1.4**
Child Acute Bronchitis Episodes	19.0	31.3	**50.3**	32.6	53.6	**86.2**	46.1	75.9	**122.0**
Respiratory Emergency Room Visits	1.5	2.6	**4.2**	1.8	3.1	**4.9**	2.1	3.6	**5.7**
Respiratory Hospital Admissions	0.4	0.7	**1.1**	0.4	0.8	**1.2**	0.5	0.9	**1.4**
Restricted Activity Days	5321.5	8996.2	**14317.7**	6199.5	10480.4	**16679.9**	7076.9	11963.8	**19040.8**
Chronic Exposure Mortality	5.2	9.1	**14.3**	6.2	10.7	**16.9**	7.1	12.3	**19.4**

Table 40
Estimated Health Outcome Due to SOA Decreases (January-December) From the Implementation of the Modified AirCare Program in the Canadian LFV

	Number of Incidences								
	25th Percentile			Central Estimate			75th Percentile		
Health Outcomes	**2011-2015**	**2016-2020**	**2011-2020**	**2011-2015**	**2016-2020**	**2011-2020**	**2011-2015**	**2016-2020**	**2011-2020**
	FVRD								
Acute Respiratory Symptom Days	975.8	1669.4	**2645.2**	2432.1	4184.5	**6616.7**	3894.1	6710.5	**10604.5**
Adult Chronic Bronchitis Cases	1.0	1.7	**2.7**	1.5	2.6	**4.1**	2.0	3.5	**5.5**
Asthma Symptom Days	41.0	70.8	**111.7**	72.7	125.6	**198.4**	104.4	180.4	**284.9**
Cardiac Emergency Room Visits	0.0	0.0	**0.0**	0.0	0.1	**0.1**	0.1	0.1	**0.2**
Cardiac Hospital Admissions	0.1	0.2	**0.3**	0.1	0.2	**0.4**	0.2	0.3	**0.4**
Child Acute Bronchitis Episodes	6.4	10.9	**17.3**	11.0	18.7	**29.7**	15.6	26.5	**42.1**
Respiratory Emergency Room Visits	0.5	0.8	**1.3**	0.6	1.0	**1.6**	0.6	1.1	**1.8**
Respiratory Hospital Admissions	0.1	0.2	**0.3**	0.1	0.2	**0.4**	0.2	0.3	**0.4**
Restricted Activity Days	1411.6	2453.8	**3865.4**	1644.2	2858.2	**4502.4**	1877.0	3262.8	**5139.8**
Chronic Exposure Mortality	1.6	2.9	**4.5**	1.9	3.4	**5.3**	2.2	3.9	**6.1**
	GVRD								
Acute Respiratory Symptom Days	12238.5	20895.0	**33133.5**	32566.2	55908.2	**88474.4**	52920.5	90983.5	**143904.0**
Adult Chronic Bronchitis Cases	14.3	24.8	**39.1**	21.9	38.0	**59.9**	29.5	51.2	**80.7**
Asthma Symptom Days	571.4	983.9	**1555.3**	1014.2	1746.5	**2760.7**	1456.7	2508.4	**3965.1**
Cardiac Emergency Room Visits	0.1	0.1	**0.2**	0.5	1.0	**1.5**	1.0	1.8	**2.8**
Cardiac Hospital Admissions	1.4	2.6	**4.0**	1.7	3.1	**4.8**	2.0	3.6	**5.5**
Child Acute Bronchitis Episodes	73.6	124.8	**198.4**	126.2	213.8	**340.0**	178.7	302.7	**481.4**
Respiratory Emergency Room Visits	5.9	8.4	**14.3**	7.0	12.5	**19.5**	8.0	11.3	**19.3**
Respiratory Hospital Admissions	1.5	2.2	**3.7**	1.7	3.1	**4.8**	1.9	2.7	**4.7**
Restricted Activity Days	20850.2	28667.4	**49517.7**	24286.4	41992.3	**66278.7**	27724.1	38118.4	**65842.5**
Chronic Exposure Mortality	20.4	36.4	**56.8**	24.0	42.8	**66.8**	27.5	49.2	**76.8**
	CDN LFV								
Acute Respiratory Symptom Days	13214.3	22564.4	**35778.7**	34998.3	60092.7	**95091.1**	56814.6	97694.0	**154508.6**
Adult Chronic Bronchitis Cases	15.2	26.5	**41.7**	23.4	40.6	**64.0**	31.5	54.7	**86.2**
Asthma Symptom Days	612.3	1054.7	**1667.0**	1087.0	1872.2	**2959.1**	1561.1	2688.9	**4250.0**
Cardiac Emergency Room Visits	0.1	0.2	**0.2**	0.6	1.0	**1.6**	1.1	1.9	**3.0**
Cardiac Hospital Admissions	1.5	2.8	**4.3**	1.8	3.3	**5.1**	2.1	3.8	**6.0**
Child Acute Bronchitis Episodes	80.1	135.7	**215.7**	137.2	232.5	**369.7**	194.3	329.2	**523.5**
Respiratory Emergency Room Visits	6.4	9.2	**15.7**	7.6	13.5	**21.0**	8.7	12.5	**21.1**
Respiratory Hospital Admissions	1.6	2.4	**4.0**	1.9	3.3	**5.2**	2.1	3.0	**5.1**
Restricted Activity Days	22261.8	31121.2	**53383.0**	25930.6	44850.5	**70781.2**	29601.1	41381.2	**70982.2**
Chronic Exposure Mortality	22.0	39.3	**61.3**	25.9	46.2	**72.1**	29.7	53.1	**82.9**

Table 41
Estimated Health Outcome Due to SOA Decreases (May-September) From the Implementation of the Modified AirCare Program in the Canadian LFV

Health Outcomes	Number of Incidences								
	25th Percentile			Central Estimate			75th Percentile		
	2011-2015	2016-2020	2011-2020	2011-2015	2016-2020	2011-2020	2011-2015	2016-2020	2011-2020
	FVRD								
Acute Respiratory Symptom Days	400.1	684.4	1084.5	997.2	1715.7	2712.8	1596.6	2751.3	4347.9
Adult Chronic Bronchitis Cases	0.4	0.7	1.1	0.6	1.1	1.7	0.8	1.4	2.3
Asthma Symptom Days	16.8	29.0	45.8	29.8	51.5	81.3	42.8	74.0	116.8
Cardiac Emergency Room Visits	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Cardiac Hospital Admissions	0.0	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.2
Child Acute Bronchitis Episodes	2.6	4.5	7.1	4.5	7.7	12.2	6.4	10.8	17.2
Respiratory Emergency Room Visits	0.2	0.3	0.5	0.2	0.4	0.6	0.3	0.5	0.7
Respiratory Hospital Admissions	0.0	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.2
Restricted Activity Days	578.8	1006.0	1584.8	674.1	1171.9	1846.0	769.6	1337.7	2107.3
Chronic Exposure Mortality	0.7	1.2	1.8	0.8	1.4	2.2	0.9	1.6	2.5
	GVRD								
Acute Respiratory Symptom Days	5017.8	8566.9	13584.7	13352.1	22922.4	36274.5	21697.4	37303.2	59000.6
Adult Chronic Bronchitis Cases	5.9	10.2	16.0	9.0	15.6	24.6	12.1	21.0	33.1
Asthma Symptom Days	234.3	403.4	637.7	415.8	716.1	1131.9	597.2	1028.5	1625.7
Cardiac Emergency Room Visits	0.0	0.1	0.1	0.2	0.4	0.6	0.4	0.7	1.1
Cardiac Hospital Admissions	0.6	1.1	1.6	0.7	1.3	2.0	0.8	1.5	2.3
Child Acute Bronchitis Episodes	30.2	51.2	81.3	51.7	87.7	139.4	73.2	124.1	197.4
Respiratory Emergency Room Visits	2.4	3.4	5.9	2.9	5.1	8.0	3.3	4.6	7.9
Respiratory Hospital Admissions	0.6	0.9	1.5	0.7	1.3	2.0	0.8	1.1	1.9
Restricted Activity Days	8548.6	11753.6	20302.2	9957.4	17216.9	27174.3	11366.9	15628.5	26995.4
Chronic Exposure Mortality	8.4	14.9	23.3	9.8	17.6	27.4	11.3	20.2	31.5
	CDN LFV								
Acute Respiratory Symptom Days	5417.9	9251.4	**14669.3**	14349.3	24638.0	**38987.3**	23294.0	40054.5	**63348.5**
Adult Chronic Bronchitis Cases	6.2	10.9	**17.1**	9.6	16.7	**26.2**	12.9	22.4	**35.3**
Asthma Symptom Days	251.1	432.4	**683.5**	445.7	767.6	**1213.2**	640.1	1102.4	**1742.5**
Cardiac Emergency Room Visits	0.0	0.1	**0.1**	0.2	0.4	**0.7**	0.4	0.8	**1.2**
Cardiac Hospital Admissions	0.6	1.1	**1.8**	0.8	1.4	**2.1**	0.9	1.6	**2.4**
Child Acute Bronchitis Episodes	32.8	55.6	**88.4**	56.2	95.3	**151.6**	79.6	135.0	**214.6**
Respiratory Emergency Room Visits	2.6	3.8	**6.4**	3.1	5.5	**8.6**	3.6	5.1	**8.7**
Respiratory Hospital Admissions	0.7	1.0	**1.6**	0.8	1.4	**2.1**	0.9	1.2	**2.1**
Restricted Activity Days	9127.3	12759.7	**21887.0**	10631.6	18388.7	**29020.3**	12136.4	16966.3	**29102.7**
Chronic Exposure Mortality	9.0	16.1	**25.1**	10.6	19.0	**29.6**	12.2	21.8	**34.0**

Table 38 indicates that there could potentially be 41 fewer incidences of chronic exposure mortality in the LFV over the period 2011-2020 for the continuation of the current AirCare program, but only 17 fewer deaths (Table 39) if the SOA conversion factors are assumed to apply only during the period May-September. By comparison, the implementation of a modified AirCare program would result in 72 fewer cases of premature mortality (Table 40) if the SOA conversion factors are applied year-round, versus 30 fewer deaths (Table 41) if the factors are applied only during the period May-September.

Apart from reducing the incidences of premature mortality, there would be significant reductions in both acute respiratory symptom days and restricted activity days for both the current and modified AirCare programs, although the modified AirCare program would be about 70% more effective than the current AirCare program.

Table 42 lists the potential health benefits of the CO reductions from both the current and modified AirCare programs. Using changes in 1-hour average CO concentrations, AQBAT calculates the benefits only in terms of reduced cardiac emergency room visits. Table 42 indicates that there would be 1,536 fewer emergency room visits in the LFV for the continuation of the current AirCare program, and up to 2,326 fewer visits for the modified AirCare program.

With respect to air toxics, and excluding $PM_{2.5}$ which is already addressed above, the four substances in the list of top air toxics risk contributors that would be affected by the AirCare program are the VOCs acetaldehyde, benzene, 1,3-butadiene, and formaldehyde. For these compounds, the relative change in cancer risk can be calculated relative to the risk level estimated for the year 2000 inventory prepared for the LFV (Levelton 2007, op. cit.). According to the latter report, the overall 70-year lifetime cancer risk in the GVRD from all sources of air toxics emissions was 526 incidences per million population, while that for the FVRD was 435 incidences per million population. The relative contributions to these risk levels from the four VOCs associated with LDV emissions are listed in Table 43.

The data in Table 43 indicate that approximately 73% of the lifetime cancer risk is attributable to Diesel particulate matter, while only 13.6% of the cancer risk is attributable to the four air toxics associated with LDV emissions. (It is unclear from the Levelton report why the acetaldehyde risk for the FVRD is 5 while the risk for the GVRD is not quantified. Similarly, it is unclear why the formaldehyde risk in the FVRD is also not quantified.)

Table 42
Estimated AirCare Benefits from Reductions in Cardiac Emergency Room Visits Due to CO Reductions in the Canadian LFV

Time Period	Number of Incidences		
	FVRD	**GVRD**	**CDN LFV**
2011-2015	**Current AirCare Program**		
25th percentile	63.2	459.4	**522.6**
Central estimate	91.8	667.5	**759.2**
75the percentile	120.4	875.4	**995.8**
2016-2020			
25th percentile	64.6	469.9	**534.5**
Central estimate	93.9	682.7	**776.6**
75the percentile	123.2	895.4	**1018.6**
2011-2020			
25th percentile	127.8	929.3	**1057.1**
Central estimate	185.7	1350.1	**1535.8**
75the percentile	243.5	1770.8	**2014.4**
2011-2015	**Modified AirCare Program**		
25th percentile	64.2	466.9	**531.0**
Central estimate	93.3	678.7	**772.0**
75the percentile	122.4	890.0	**1012.3**
2016-2020			
25th percentile	129.2	939.4	**1068.7**
Central estimate	187.9	1365.7	**1553.6**
75the percentile	246.4	1790.8	**2037.2**
2011-2020			
25th percentile	193.4	1406.3	**1599.7**
Central estimate	281.2	2044.4	**2325.6**
75the percentile	368.7	2680.8	**3049.6**

Table 43
Air Toxics Cancer Risks in the Canadian Portion of the LFV in 2000

Air Toxic Substance	Cancer Risk (incidences per million population)		
	GVRD	**FVRD**	**CDN LFV**
Diesel PM	350	350	700
Acetaldehyde		5	5
Benzene	41	12	53
1,3-Butadiene	39	10	49
Carbon Tetrachloride	29	29	58
Chromium VI	14	11	25
Formaldehyde	24		24
22 other substances	28	19	47
Total	**526**	**435**	**961**

Source: Levelton 2007

The air toxics risk assessment for the LFV also estimated that the overall cancer risk for the period 2005 to 2020 was projected to decrease as follows:

Year	Cancer Risk (incidences per million population)		
	GVRD	**FVRD**	**CDN LFV**
2005	472	360	832
2010	449	298	747
2015	424	233	657
2020	418	187	605

Using the ratio of the estimated emissions for the four air toxics in 2000 (Levelton 2007, op. cit.) and the emissions estimated in Table 26, the total risk levels for the LFV with and without the AirCare program are estimated as listed in Table 44. The data indicate that the modified AirCare program would provide a marginal improvement in reduced overall lifetime cancer risk from all sources as compared with the continuation of the current AirCare program. By 2020, the overall lifetime cancer risk from air toxics emissions in the LFV would be 1.57% lower for the modified AirCare program, compared with only 0.87% lower for the continuation of the current AirCare program.

Figure 39 shows the differences in the combined cancer risks posed by the four air toxics between the No I/M scenarios 1 and 2, and the current (Scenario 3) and modified (Scenario 4) AirCare programs. Figure 40 shows the same differences relative to the total cancer risk in the LFV for all sources of toxic air contaminants. The trend lines show that overall cancer risk in the LFV would decline over the period 2010 to 2020 with or without the AirCare program, but that the reduction would be slightly larger with AirCare.

Table 44
Projected LDV Air Toxics Cancer Risks

I/M Case	Species	Lifetime Cancer Risk (incidences per million population)			
		2005	**2010**	**2015**	**2020**
None, MOBILE No I/M Baseline	Total Benzene	22.0	14.4	11.0	9.9
	Exhaust Acetaldehyde	2.7	1.7	1.2	1.1
	Exhaust Butadiene	3.5	2.1	1.4	1.3
	Exhaust Formaldehyde	8.0	4.8	3.3	3.0
	Total Risk	**36.1**	**23.0**	**16.9**	**15.3**
None, Modified No I/M Baseline	Total Benzene		16.2	13.7	13.3
	Exhaust Acetaldehyde		1.9	1.4	1.3
	Exhaust Butadiene		2.1	1.4	1.3
	Exhaust Formaldehyde		4.8	3.3	3.0
	Total Risk		**24.9**	**19.8**	**18.9**
Current Program	Total Benzene	17.5	11.3	8.0	6.4
	Exhaust Acetaldehyde	2.2	1.4	0.9	0.8
	Exhaust Butadiene	2.7	1.6	1.0	0.8
	Exhaust Formaldehyde	6.3	3.9	2.5	2.1
	Total Risk	**28.6**	**18.3**	**12.3**	**10.0**
Modified Program	Total Benzene		10.7	7.5	6.0
	Exhaust Acetaldehyde		1.4	0.9	0.7
	Exhaust Butadiene		1.6	1.0	0.8
	Exhaust Formaldehyde		3.9	2.4	2.0
	Total Risk		**17.5**	**11.8**	**9.5**

Figure 39
Trend in Lifetime Cancer Risk in the LFV Associated with LDV Emissions

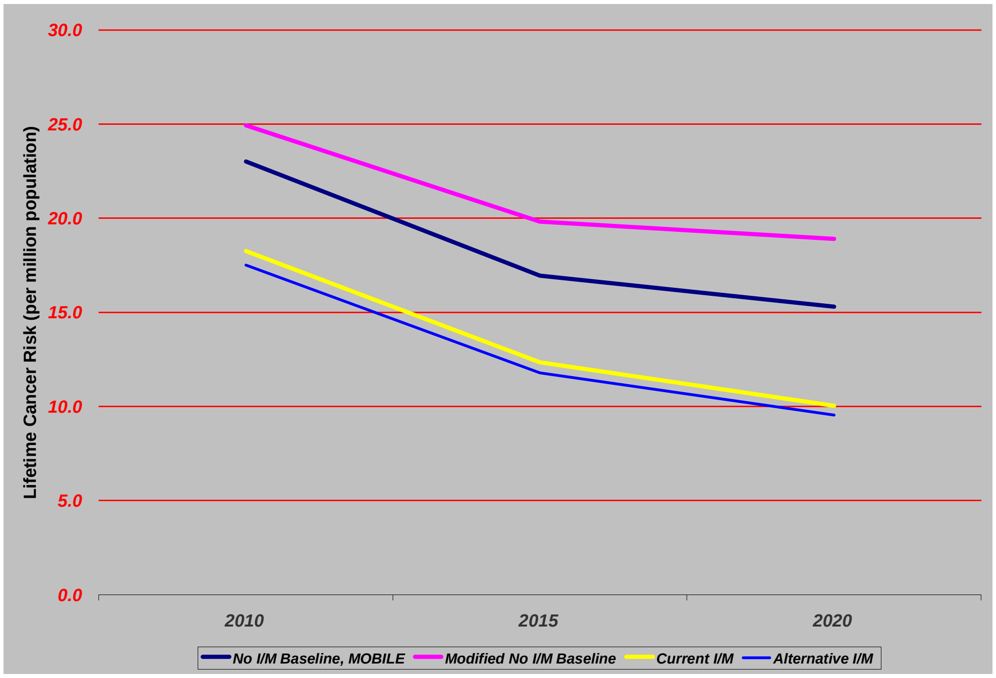
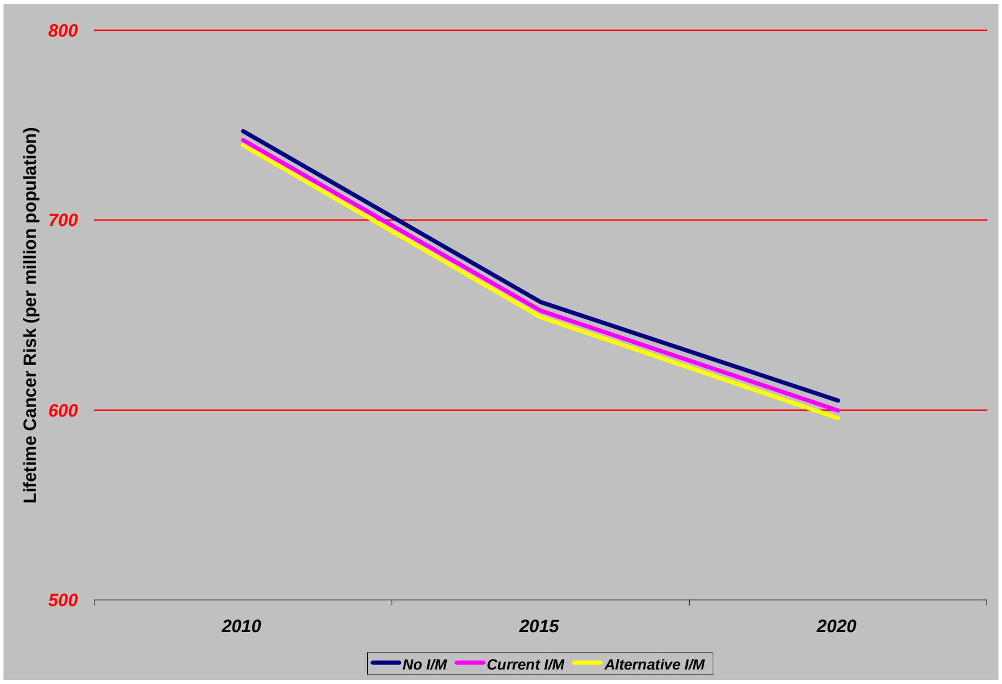


Figure 40
Trend in Overall Lifetime Cancer Risk from Air Toxics Emissions in the LFV



8.3.2 Potential Economic Costs and Benefits – The AQBAT monetary valuation of the health benefits discussed above are presented in Tables 45 through 49 for NO_2, O_3, $PM_{2.5}$ (as SOA), and CO. The O_3 valuation is considered hypothetical in that it may not be realized. The valuation of $PM_{2.5}$ health outcomes is presented both for when the SOA conversion factors are applied year round and for when they are applied only for the period May-September. The latter represents the minimum monetary benefits of the current or modified AirCare programs, while the former represents the upper bound estimate of the programs. The 25th percentile valuation indicates that there is only a 25% chance that the monetary benefits of AirCare are less than these values, while the 75th percentile indcates that there is only a 25% chance that the benefits of AirCare may be greater than these values.

With respect to lifetime cancer risk from air toxics, it was not possible to estimate any economic benefits from the change in risk from air toxics due to AirCare. The reasons for this are outlined below.

1. The AQBAT modules used for estimating health effects only deal with the following air pollutants: CO, NO_2, O_3, SO_2, $PM_{2.5}$ and PM_{10}. No other chemicals are present.

2. The only toxicological data available are for the calculation of risks. To the best of our knowledge, there are no readily available epidemiological data to couple the decrease in risk from particular air toxic to a decrease in mortality rate for these compounds. Thus, for a decrease in concentration, it was only the calculation of a reduction of health risk was possible for the evaluation of the AirCare program.

3. Even if it were possible to calculate the number of excess cancer hospitalizations that would be avoided in the LFV due to reductions in air toxics emissions, these will not necessarily translate into excess mortality—some cancers are curable.

4. The cost factors in AQBAT for hospitalization and treatment are not appropriate for cancer treatment. In order to couple the risk reduction to mortality and economic benefit, a model would have to be constructed that would be complex and require a substantial amount of time and money. Therefore, it would require a major survey of cancer treatment costs to even begin to estimate what those cost values might be. This is beyond the scope of work for this review, and could never be completed within the short time available.

Table 45 indicates that the central estimate of potential monetary benefits from the reduction in annual average NO_2 concentrations in the Canadian portion of the LFV due to the continuation of the current AirCare program is $133.2 million CDN (in undiscounted 2010 dollars) for the period 2011-2020, and $483.6 million CDN (in undiscounted 2010 dollars) for the modified AirCare program. These benefits are all attributable to reduced acute exposure mortality.

Table 45
Estimated Monetary Valuation of Health Effects Benefits Due to NO_2 Reduction in the Canadian LFV

Time Period	Monetary Valuation ($2010)		
	FVRD	**GVRD**	**CDN LFV**
2011-2015	**Current AirCare Program**		
25th percentile	$2,452,279	$18,618,185	**$21,070,464**
Central estimate	$4,104,908	$31,165,264	**$35,270,172**
75th percentile	$5,037,724	$38,247,391	**$43,285,115**
2016-2020			
25th percentile	$4,378,731	$54,148,779	**$58,527,510**
Central estimate	$7,329,625	$90,640,609	**$97,970,234**
75th percentile	$8,995,240	$111,237,308	**$120,232,548**
2011-2020			
25th percentile	$6,831,010	$72,766,964	**$79,597,975**
Central estimate	$11,434,532	$121,805,873	**$133,240,406**
75th percentile	$14,032,964	$149,484,699	**$163,517,663**
2011-2015	**Modified AirCare Program**		
25th percentile	$7,421,207	$75,121,359	**$82,542,565**
Central estimate	$12,313,801	$124,647,071	**$136,960,872**
75th percentile	$15,061,085	$152,458,682	**$167,519,767**
2016-2020			
25th percentile	$21,552,807	$239,501,416	**$261,054,223**
Central estimate	$35,762,168	$397,402,706	**$433,164,874**
75th percentile	$37,103,584	$412,324,032	**$449,427,615**
2011-2020			
25th percentile	$24,576,654	$266,872,763	**$291,449,417**
Central estimate	$40,779,523	$442,818,758	**$483,598,282**
75th percentile	$49,878,862	$541,644,199	**$591,523,060**

Note: Future costs and benefits not discounted for inflation.

Table 46 lists the hypothetical benefits of a 0.2 ppb reduction in maximum daily 1-hour average O_3 concentrations due to the current AirCare program and a 0.5 ppb reduction due to the modified AirCare program over the period 2011-2020. Continuation of the current AirCare program could potentially result in $220.5 million CDN benefits (central estimate) in reduced acute exposure mortality, while implementation of the modified AirCare program would result in $551.2 million CDN.

Table 46
Estimated Monetary Valuation of Health Effects Benefits Due to O_3 Reduction in the Canadian LFV

Time Period	**Monetary Valuation ($2010)**		
	FVRD	**GVRD**	**CDN LFV**
2011-2015	**Current AirCare Program**		
25th percentile	$5,787,360	$43,938,775	**$49,726,135**
Central estimate	$9,208,175	$69,910,269	**$79,118,444**
75th percentile	$10,322,452	$78,370,083	**$88,692,535**
2016-2020			
25th percentile	$10,333,772	$78,543,553	**$88,877,325**
Central estimate	$25,650,071	$194,879,638	**$220,529,709**
75th percentile	$28,753,976	$218,461,944	**$247,215,920**
2011-2020			
25th percentile	$16,121,132	$122,482,328	**$138,603,460**
Central estimate	$25,650,071	$194,879,638	**$220,529,709**
75th percentile	$28,753,976	$218,461,944	**$247,215,920**
2011-2015	**Modified AirCare Program**		
25th percentile	$14,377,439	$109,156,338	**$123,533,776**
Central estimate	$23,017,539	$174,753,680	**$197,771,220**
75th percentile	$25,764,750	$195,611,040	**$221,375,789**
2016-2020			
25th percentile	$25,672,012	$195,124,389	**$220,796,401**
Central estimate	$41,099,569	$312,384,107	**$353,483,677**
75th percentile	$46,004,923	$349,668,058	**$395,672,980**
2011-2020			
25th percentile	$40,049,450	$304,280,727	**$344,330,177**
Central estimate	$64,117,109	$487,137,788	**$551,254,897**
75th percentile	$71,769,672	$545,279,098	**$617,048,770**

Note: Future costs and benefits not discounted for inflation

Table 47 indicates that the net benefits of the current AirCare program in reduced $PM_{2.5}$ concentrations (as SOA) due to reduced VOC emissions over the period 2011-2020 would amount to $261 million CDN (central estimate) if the SOA conversion factors are applied year-round, versus $107 million CDN if the factors are applicable only during the May-September period. Virtually all of the benefits (92.6%) are attributable to reductions in chronic exposure mortality.

Table 48 presents the same comparison for the net benefits of the modified AirCare program. The small reduction in $PM_{2.5}$ concentrations would result in a net benefit of $457 million CDN (central estimate) in reduced health effects costs if the SOA conversion factors are applied year-round, and $187.4 million CDN if the factors are applied only to the May-September period of the year.

Table 47
Monetary Valuation of Potential Health Effects Benefits from the Current AirCare Program Due to $PM_{2.5}$ Reduction in the Canadian LFV

	Monetary Valuation ($2010)					
	January-December			May-September		
Health Endpoint	**25th percentile**	**Central Estimate**	**75th Percentile**	**25th percentile**	**Central Estimate**	**75th Percentile**
Acute Respiratory Symptom Days	$5,128	$23,979	$37,758	$2,103	$9,831	$15,481
Adult Chronic Bronchitis Cases	$181,514	$346,650	$472,233	$74,421	$142,127	$193,616
Asthma Symptom Days	$1,134	$2,850	$4,095	$465	$1,168	$1,679
Cardiac Emergency Room Visits	$22	$140	$253	$9	$57	$104
Cardiac Hospital Admissions	$0	$0	$0	$0	$0	$0
Child Acute Bronchitis Episodes	$1,165	$2,605	$3,780	$477	$1,068	$1,550
Respiratory Emergency Room Visits	$704	$848	$982	$289	$348	$403
Respiratory Hospital Admissions	$0	$0	$0	$0	$0	$0
Restricted Activity Days	$41,504	$59,861	$76,317	$17,017	$24,543	$31,290
Chronic Exposure Mortality	$3,881,637	$6,182,993	$7,245,244	$1,591,471	$2,535,027	$2,970,550
All endpoints - FVRD	**$4,112,808**	**$6,619,926**	**$7,690,019**	**$1,686,251**	**$2,714,170**	**$3,152,908**
Acute Respiratory Symptom Days	$180,341	$942,081	$1,499,603	$73,940	$386,253	$614,837
Adult Chronic Bronchitis Cases	$7,873,287	$15,034,833	$20,481,898	$3,228,048	$6,164,282	$8,397,578
Asthma Symptom Days	$46,480	$116,837	$167,913	$19,057	$47,903	$68,844
Cardiac Emergency Room Visits	$839	$5,407	$9,811	$344	$2,217	$4,022
Cardiac Hospital Admissions	$0	$0	$0	$0	$0	$0
Child Acute Bronchitis Episodes	$38,817	$86,807	$125,967	$15,915	$35,591	$51,646
Respiratory Emergency Room Visits	$26,517	$31,929	$36,969	$10,872	$13,091	$15,157
Respiratory Hospital Admissions	$0	$0	$0	$0	$0	$0
Restricted Activity Days	$1,806,879	$2,606,029	$3,322,406	$740,820	$1,068,472	$1,362,186
Chronic Exposure Mortality	$147,859,000	$235,523,832	$275,983,376	$60,622,190	$96,564,771	$113,153,184
All endpoints - GVRD	**$161,263,456**	**$254,347,755**	**$295,414,267**	**$66,118,017**	**$104,282,580**	**$121,119,850**
Acute Respiratory Symptom Days	$185,469	$966,060	$1,537,361	$76,042	$396,085	$630,318
Adult Chronic Bronchitis Cases	$8,054,801	$15,381,483	$20,954,131	$3,302,468	$6,306,408	$8,591,194
Asthma Symptom Days	$47,614	$119,686	$172,008	$19,522	$49,071	$70,523
Cardiac Emergency Room Visits	$861	$5,547	$10,064	$353	$2,274	$4,126
Cardiac Hospital Admissions	$0	$0	$0	$0	$0	$0
Child Acute Bronchitis Episodes	$39,981	$89,412	$129,747	$16,392	$36,659	$53,196
Respiratory Emergency Room Visits	$27,221	$32,777	$37,951	$11,161	$13,439	$15,560
Respiratory Hospital Admissions	$0	$0	$0	$0	$0	$0
Restricted Activity Days	$1,848,383	$2,665,891	$3,398,723	$757,837	$1,093,015	$1,393,476
Chronic Exposure Mortality	$151,740,637	$241,706,825	$283,228,621	$62,213,661	$99,099,798	$116,123,734
All endpoints - CDN LFV	**$165,376,264**	**$260,967,682**	**$303,104,287**	**$67,804,268**	**$106,996,749**	**$124,272,757**

Note: Future costs and benefits not discounted for inflation

Table 48
Monetary Valuation of Potential Health Effects Benefits from the Modified AirCare Program Due to $PM_{2.5}$ Reduction in the Canadian LFV

Health Endpoint	Monetary Valuation ($2010)					
	January-December			**May-September**		
	25th percentile	**Central Estimate**	**75th percentile**	**25th percentile**	**Central Estimate**	**75th percentile**
Acute Respiratory Symptom Days	$24,282	$117,429	$191,354	$9,956	$48,146	$78,455
Adult Chronic Bronchitis Cases	$911,333	$1,713,844	$2,312,330	$373,646	$702,676	$948,055
Asthma Symptom Days	$5,609	$13,991	$20,042	$2,300	$5,736	$8,217
Cardiac Emergency Room Visits	$109	$711	$1,301	$45	$291	$533
Cardiac Hospital Admissions	$0	$0	$0	$0	$0	$0
Child Acute Bronchitis Episodes	$5,705	$12,636	$18,182	$2,339	$5,181	$7,455
Respiratory Emergency Room Visits	$3,547	$4,253	$4,924	$1,454	$1,744	$2,019
Respiratory Hospital Admissions	$0	$0	$0	$0	$0	$0
Restricted Activity Days	$205,815	$295,038	$377,505	$84,384	$120,966	$154,777
Chronic Exposure Mortality	$19,115,402	$30,999,663	$36,304,473	$7,837,315	$12,709,862	$14,884,834
All endpoints - FVRD	**$21,330,746**	**$33,157,564**	**$38,569,655**	**$8,745,606**	**$13,594,601**	**$15,813,559**
Acute Respiratory Symptom Days	$295,220	$1,570,192	$2,591,088	$121,040	$643,779	$1,062,346
Adult Chronic Bronchitis Cases	$13,322,956	$25,054,748	$33,804,606	$5,462,412	$10,272,447	$13,859,889
Asthma Symptom Days	$78,068	$194,728	$278,937	$32,008	$79,838	$114,364
Cardiac Emergency Room Visits	$1,323	$9,012	$16,550	$542	$3,695	$6,786
Cardiac Hospital Admissions	$0	$0	$0	$0	$0	$0
Child Acute Bronchitis Episodes	$65,307	$144,639	$208,132	$26,776	$59,302	$85,334
Respiratory Emergency Room Visits	$38,442	$53,215	$53,376	$15,761	$21,818	$21,884
Respiratory Hospital Admissions	$0	$0	$0	$0	$0	$0
Restricted Activity Days	$2,636,647	$4,343,174	$4,836,100	$1,081,025	$1,780,701	$1,982,801
Chronic Exposure Mortality	$242,034,965	$392,513,186	$459,675,391	$99,234,336	$160,930,406	$188,466,910
All endpoints - GVRD	**$274,497,468**	**$423,882,893**	**$493,042,208**	**$112,543,962**	**$173,791,986**	**$202,147,305**
Acute Respiratory Symptom Days	$319,502	$1,687,621	$2,782,442	$130,996	$691,924	$1,140,801
Adult Chronic Bronchitis Cases	$14,234,289	$26,768,592	$36,116,937	$5,836,058	$10,975,123	$14,807,944
Asthma Symptom Days	$83,678	$208,719	$298,979	$34,308	$85,575	$122,581
Cardiac Emergency Room Visits	$1,432	$9,723	$17,851	$587	$3,986	$7,319
Cardiac Hospital Admissions	$0	$0	$0	$0	$0	$0
Child Acute Bronchitis Episodes	$71,012	$157,275	$226,314	$29,115	$64,483	$92,789
Respiratory Emergency Room Visits	$41,988	$57,468	$58,300	$17,215	$23,562	$23,903
Respiratory Hospital Admissions	$0	$0	$0	$0	$0	$0
Restricted Activity Days	$2,842,462	$4,638,212	$5,213,605	$1,165,409	$1,901,667	$2,137,578
Chronic Exposure Mortality	$261,150,367	$423,512,849	$495,979,864	$107,071,650	$173,640,268	$203,351,744
All endpoints - CDN LFV	**$295,828,214**	**$457,040,458**	**$531,611,863**	**$121,289,568**	**$187,386,588**	**$217,960,864**

Note: Future costs and benefits not discounted for inflation.

Table 49 lists the potential benefits of reduced CO concentrations from reduced cardiac emergency room visits. The AQBAT evaluation indicates that there would be $10.9 million CDN (central estimate) in net benefits from the continuation of the current AirCare program, and $16.5 million CDN in benefits from the implementation of the modified AirCare program over the period 2011-2020.

Table 49
Estimated Monetary Valuation of Health Effects Benefits Due to CO Reduction in the Canadian LFV

Time Period	Monetary Valuation ($2010)		
	FVRD	**GVRD**	**CDN LFV**
2011-2015	**Current AirCare Program**		
25th percentile	$442,796	$3,220,929	**$3,663,724**
Central Estimate	$651,386	$4,738,227	**$5,389,613**
75th percentile	$853,720	$6,210,020	**$7,063,740**
2016-2020			
25th percentile	$453,216	$3,294,367	**$3,747,583**
Central Estimate	$666,714	$4,846,261	**$5,512,975**
75th percentile	$873,810	$6,351,611	**$7,225,421**
2011-2020			
25th percentile	$896,012	$6,515,296	**$7,411,307**
Central Estimate	$1,318,100	$9,584,487	**$10,902,588**
75th percentile	$1,727,530	$12,561,631	**$14,289,161**
2011-2015	**Modified AirCare Program**		
25th percentile	$446,667	$3,248,781	**$3,695,448**
Central Estimate	$662,428	$4,818,102	**$5,480,531**
75th percentile	$870,634	$6,332,461	**$7,203,095**
2016-2020			
25th percentile	$899,361	$6,537,249	**$7,436,610**
Central Estimate	$1,333,796	$9,695,061	**$11,028,857**
75th percentile	$1,753,016	$12,742,279	**$14,495,295**
2011-2020			
25th percentile	$1,346,027	$9,786,031	**$11,132,058**
Central Estimate	$1,996,224	$14,513,164	**$16,509,388**
75th percentile	$2,623,650	$19,074,740	**$21,698,390**

Note: Future costs and benefits not discounted for inflation.

8.3.3 Summary and Conclusions – The assessment of the potential benefits associated with either the continuation of the current AirCare program or with the implementation of a modified AirCare program in 2011 indicates that those benefits would largely be related to reductions in acute or chronic mortality related to NO_2 and SOA in $PM_{2.5}$, with some additional benefits from reductions in secondary organic aerosol formation and minor benefits from reductions in CO emissions. The benefits from reductions in O_3 concentrations are considered to be hypothetical, and unlikely to be realized based on current understanding of the LFV airshed. There would also be a reduction in lifetime cancer risks due to reductions in selected air toxics in VOC emissions.

Table 50a provides a summary of the primary health outcome benefits in the Canadian portion of the LFV for both the continuation of the current AirCare program and the implementation of a modified Aircare program. The $PM_{2.5}$ benefits in Table 50a assume that the SOA conversion factors are applicable over the entire year. It is estimated that there could be 117 fewer deaths over the period 2011-2020 from the continuation of the AirCare program if the hypothetical effects of reduced O_3 concentrations are included. By comparison, the implementation of a modified AirCare program could result in 306 fewer cases of premature mortality over the same period.

Table 50b lists the same benefits, but excluding the hypothetical benefits of reduced O_3 concentrations and limiting the benefits of reduced $PM_{2.5}$ concentrations to the May-September period. Under these assumptions, the continuation of the current AirCare program over the period 2011-2020 would result in 47 fewer premature deaths, while the implementation of a modified AirCare program would result in 153 fewer cases of premature mortality.

Due to the significant uncertainty posed by the issue of seasonal variability in SOA formation, Table 50c lists the potential health benefits based on the SOA conversion factors provided by Environment Canada (Table 30) for the period May-September, but assuming that the SOA formation is reduced by a factor of three in the colder months of the year (November-April). Table 50c also excludes any benefits from reductions in O_3. Table 50c is considered to provide a more reliable estimate of the potential benefits of the current and modified AirCare programs. The data in Table 50c suggest that the continuation of the current AirCare program would result in 47 fewer cases of premature mortality (central estimate), compared with 140 fewer cases for the modified AirCare program over the period 2011-2020.

Table 50a
Summary of Potential Health Benefits of AirCare in the LFV (2011-2020)

Contaminant	Health Outcome	Number of Incidences		
		25th percentile	Central Estimate	75th percentile
			Current AirCare Program	
NO$_2$	Acute Exposure Mortality	17.6	22.7	27.8
O$_3$	Acute Exposure Mortality	33.4	37.5	41.6
PM$_{2.5}$	Acute Respiratory Symptom Days	19969.1	54433.9	87879.4
	Adult Chronic Bronchitis Cases	24.0	36.8	49.5
	Asthma Symptom Days	956.8	1696.8	2436.6
	Cardiac Emergency Room Visits	0.1	0.9	1.7
	Cardiac Hospital Admissions	2.5	2.9	3.4
	Child Acute Bronchitis Episodes	122.7	210.2	297.6
	Respiratory Emergency Room Visits	10.2	12.0	13.8
	Respiratory Hospital Admissions	2.6	3.0	3.3
	Restricted Activity Days	34921.1	40682.7	46441.0
	Chronic Exposure Mortality	35.0	41.1	47.3
CO	Cardiac Emergency Room Visits	1057.1	1535.8	2014.4
Air Toxics	Lifetime Cancer Risk Reduction		0.87%	
			Modified AirCare Program	
NO$_2$	Acute Exposure Mortality	75.2	97.0	118.8
O$_3$	Acute Exposure Mortality	83.6	93.6	104.1
PM$_{2.5}$	Acute Respiratory Symptom Days	35778.7	95091.1	154508.6
	Adult Chronic Bronchitis Cases	41.7	64.0	86.2
	Asthma Symptom Days	1667.0	2959.1	4250.0
	Cardiac Emergency Room Visits	0.2	1.6	3.0
	Cardiac Hospital Admissions	4.3	5.1	6.0
	Child Acute Bronchitis Episodes	215.7	369.7	523.5
	Respiratory Emergency Room Visits	15.7	21.0	21.1
	Respiratory Hospital Admissions	4.0	5.2	5.1
	Restricted Activity Days	53383.0	70781.2	70982.2
	Chronic Exposure Mortality	61.3	72.1	82.9
CO	Cardiac Emergency Room Visits	1599.7	2325.6	3049.6
Air Toxics	Lifetime Cancer Risk Reduction		1.57%	

Notes:
- Hypothetical O$_3$ benefits
- Assumes SOA conversion factors apply year round

Table 50b
Summary of Potential Health Benefits of AirCare in the LFV (2011-2020)

Contaminant	Health Outcome	Number of Incidences 25th percentile	Central Estimate	75th percentile
		Current AirCare Program		
NO_2	Acute Exposure Mortality	17.6	22.7	27.8
O_3	Acute Exposure Mortality	0	0	0
$PM_{2.5}$	Acute Respiratory Symptom Days	8187.3	22317.9	36030.5
	Adult Chronic Bronchitis Cases	9.8	15.1	20.3
	Asthma Symptom Days	392.3	695.7	999.0
	Cardiac Emergency Room Visits	0.1	0.4	0.7
	Cardiac Hospital Admissions	1.0	1.2	1.4
	Child Acute Bronchitis Episodes	50.3	86.2	122.0
	Respiratory Emergency Room Visits	4.2	4.9	5.7
	Respiratory Hospital Admissions	1.1	1.2	1.4
	Restricted Activity Days	14317.7	16679.9	19040.8
	Chronic Exposure Mortality	14.3	16.9	19.4
CO	Cardiac Emergency Room Visits	1057.1	1535.8	2014.4
Air Toxics	Lifetime Cancer Risk Reduction		0.87%	
		Modified AirCare Program		
NO_2	Acute Exposure Mortality	75.2	97.0	118.8
O_3	Acute Exposure Mortality	0	0	0
$PM_{2.5}$	Acute Respiratory Symptom Days	14669.3	38987.3	63348.5
	Adult Chronic Bronchitis Cases	17.1	26.2	35.3
	Asthma Symptom Days	683.5	1213.2	1742.5
	Cardiac Emergency Room Visits	0.1	0.7	1.2
	Cardiac Hospital Admissions	1.8	2.1	2.4
	Child Acute Bronchitis Episodes	88.4	151.6	214.6
	Respiratory Emergency Room Visits	6.4	8.6	8.7
	Respiratory Hospital Admissions	1.6	2.1	2.1
	Restricted Activity Days	21887.0	29020.3	29102.7
	Chronic Exposure Mortality	25.1	29.6	34.0
CO	Cardiac Emergency Room Visits	1599.7	2325.6	3049.6
Air Toxics	Lifetime Cancer Risk Reduction		1.57%	

Notes:

- No O_3 benefits
- Assumes SOA conversion factors apply May-September

Table 50c
Summary of Potential Health Benefits of AirCare in the LFV (2011-2020)

Contaminant	Health Outcome	Number of Incidences		
		25th percentile	Central Estimate	75th percentile
			Current AirCare Program	
NO_2	Acute Exposure Mortality	17.6	22.7	27.8
O_3	Acute Exposure Mortality	0.0	0.0	0.0
$PM_{2.5}$	Acute Respiratory Symptom Days	11981.5	32660.3	52727.6
	Adult Chronic Bronchitis Cases	14.4	22.1	29.7
	Asthma Symptom Days	574.1	1018.1	1462.0
	Cardiac Emergency Room Visits	0.1	0.5	1.0
	Cardiac Hospital Admissions	1.5	1.7	2.0
	Child Acute Bronchitis Episodes	73.6	126.1	178.6
	Respiratory Emergency Room Visits	6.1	7.2	8.3
	Respiratory Hospital Admissions	0.8	1.8	2.0
	Restricted Activity Days	20952.7	24409.6	27864.6
	Chronic Exposure Mortality	21.0	24.7	28.4
CO	Cardiac Emergency Room Visits	1057.1	1535.8	2014.4
Air Toxics	Lifetime Cancer Risk Reduction		0.87%	
			Modified AirCare Program	
NO_2	Acute Exposure Mortality	75.2	97.0	118.8
O_3	Acute Exposure Mortality	0.0	0.0	0.0
$PM_{2.5}$	Acute Respiratory Symptom Days	21467.2	57054.7	92705.2
	Adult Chronic Bronchitis Cases	25.0	38.4	51.7
	Asthma Symptom Days	1000.2	1775.5	2550.0
	Cardiac Emergency Room Visits	0.1	0.1	1.8
	Cardiac Hospital Admissions	2.6	3.1	3.6
	Child Acute Bronchitis Episodes	129.4	221.8	314.2
	Respiratory Emergency Room Visits	9.4	12.6	12.7
	Respiratory Hospital Admissions	2.4	3.1	3.1
	Restricted Activity Days	32029.8	42468.7	42589.3
	Chronic Exposure Mortality	37.8	43.3	49.7
CO	Cardiac Emergency Room Visits	1599.7	2325.6	3049.6
Air Toxics	Lifetime Cancer Risk Reduction		1.57%	

Notes:

- No O_3 benefits
- Assumes SOA conversion factors apply May-September

Virtually all of the monetary benefits from reduced incidence of health outcomes would be related to a lower incidence of premature mortality. Table 51a indicates that the central estimate of monetary benefits for the continuation of the current Aircare program over the period 2011-2020 is $625.6 million CDN if the hypothetical O_3 benefits are included along with the application of SOA conversion factors to the entire year. The valuation of the current AirCare program is reduced to $251.1 million CDN (Table 51b) if the O_3 benefits are excluded and the effectiveness of SOA reductions is limited to the May-September period. Similarly, the potential benefits of the modified AirCare program may be as high as $1,508.4 million with the inclusion of the hypothetical O_3 benefits and the application of SOA benefits to the entire year. However, the lower bound estimate of the modified AirCare program may be reduced to $687.5 million (Table 51b) with the exclusion of the O_3 benefits and limiting the SOA benefits to the May-September season.

Table 51c provides a modified estimate of the benefits of the AirCare program which is based on the assumption that SOA conversion rates in winter are one-third the rates in summer. Table 51c indicates that the continuation of the current AirCare program would produce a total monetary benefit of $300.7 million CDN, while the implementation of the modified AirCare program would result in $774.3 million CDN in monetary benefits over the period 2011-2020.

Table 51a
Summary of Monetary Valuation Benefits of AirCare in the LFV (2011-2020)

Contaminant	Monetary Valuation ($2010)		
	25th percentile	**Central Estimate**	**75th percentile**
	Current AirCare Program		
NO_2	$79,597,565	$133,240,406	$163,517,663
O_3	$138,603,460	$220,529,709	$247,215,920
$PM_{2.5}$ (SOA)	$165,376,264	$260,967,682	$303,104,287
CO	$7,441,307	$10,902,588	$14,289,161
Total	**$391,018,596**	**$625,640,385**	**$728,127,031**
	Modified AirCare Program		
NO_2	$291,449,417	$483,598,282	$591,523,060
O_3	$344,330,177	$551,254,897	$617,048,770
$PM_{2.5}$ (SOA)	$295,828,214	$457,040,458	$531,611,863
CO	$11,132,058	$16,509,388	$21,698,390
Total	**$942,739,866**	**$1,508,403,025**	**$1,761,882,083**

Notes:

- Hypothetical O_3 benefits
- Assumes SOA conversion factors apply year round.
- Future costs and benefits not discounted for inflation.

Table 51b
Summary of Monetary Valuation Benefits of AirCare in the LFV (2011-2020)

Contaminant	Monetary Valuation ($2010)		
	25th percentile	Central Estimate	75th percentile
	Current AirCare Program		
NO_2	$79,597,565	$133,240,406	$163,517,663
O_3	$0	$0	$0
$PM_{2.5}$ (SOA)	$67,804,268	$106,996,749	$124,272,757
CO	$7,441,307	$10,902,588	$14,289,161
Total	**$154,843,140**	**$251,139,743**	**$302,079,581**
	Modified AirCare Program		
NO_2	$291,449,417	$483,598,282	$591,523,060
O_3	$0	$0	$0
$PM_{2.5}$ (SOA)	$121,289,568	$187,386,588	$217,960,864
CO	$11,132,058	$16,509,388	$21,698,390
Total	**$423,871,043**	**$687,494,258**	**$831,182,314**

Notes:

- No O_3 benefits
- Assumes SOA conversion factors apply May-September.
- Future costs and benefits not discounted for inflation.

Table 51c
Summary of Monetary Valuation Benefits of AirCare in the LFV (2011-2020)

Contaminant	Monetary Valuation ($2010)		
	25th percentile	Central Estimate	75th percentile
	Current AirCare Program		
NO_2	$79,597,565	$133,240,406	$163,517,663
O_3	$0	$0	$0
$PM_{2.5}$ (SOA)	$165,376,264	$156,580,609	$303,104,287
CO	$7,441,307	$10,902,588	$14,289,161
Total	**$186,264,630**	**$300,723,624**	**$359,669,396**
	Modified AirCare Program		
NO_2	$291,449,417	$483,598,282	$591,523,060
O_3	$0	$0	$0
$PM_{2.5}$ (SOA)	$177,496,928	$274,224,275	$318,967,118
CO	$11,132,058	$16,509,388	$21,698,390
Total	**$480,078,403**	**$774,331,945**	**$932,188,568**

Notes:

- No O_3 benefits
- Assumes SOA conversion factors apply May-September.
- Future costs and benefits not discounted for inflation.

9. Summary and Recommendations

The analysis conducted by Sierra and SENES indicates that continuation of the AirCare vehicle I/M program in a slightly revised form will provide significant reductions in vehicle emissions of unburned HC, CO, and NOx in a cost-effective manner. As our emissions analysis indicates, the replacement of older vehicles in the fleet with newer vehicles designed to meet more stringent emissions standards is reducing the impact of motor vehicles on air pollution in the metropolitan Vancouver area; however, the AirCare program is critical to maintaining a downward trend in HC emissions. In the absence of an effective I/M program, data available from the State of California demonstrate that even late-model vehicles with on-board diagnostic systems develop emissions-related defects that go uncorrected in the absence of an effective I/M program.

Because the "potential to emit" for late-model vehicles is just as great as for older vehicles, the total tonnes of emissions reduced by requiring the repair of defective vehicles is as large in the future as it is currently. In fact, modified test procedures for better identifying evaporative emissions-related defects would provide a greater emissions reduction than is being achieved by the current AirCare Program.

The current AirCare Program reduces motor vehicle emissions of HC and NOx, the principal precursors of ozone and "secondary" particulates, by approximately 20%. As properly maintained vehicles approach zero emissions, the percentage reductions associated with the repair of defective vehicles increase to about 50% by 2020. When the emissions from industrial sources and vehicles not subject to the program (e.g., heavy duty trucks, marine vessels, aircraft) are included, the effect of continuing the AirCare Program on total emissions in 2020 is a 4.7% reduction in HC and an 8.8% reduction in NOx.

In addition to reducing common air contaminants, continuation of the AirCare Program is estimated to reduce greenhouse gas emissions from motor vehicles by 1.1% and toxic air contaminants (e.g., benzene) by over 40%. With certain program changes, we estimate that a next generation of the AirCare program could reduce impact-weighted emissions by an average of 27-40% at a cost-effectiveness ratio of $2,653 to $4,863/tonne, which is competitive with the cost-effectiveness ratio of other programs that have been imposed to control emissions from other sources.

Based on the analysis of air quality and health impacts performed by SENES, continuation of a modified AirCare program through 2020 is estimated to reduce lifetime cancer risk by 1.57%. There would also be significant benefits resulting from reduced public exposure to NO_2, secondary particulate, and CO. The projected reduction in ambient NO_2 and particulate concentrations is estimated to result in 140 fewer premature deaths during the 2011-2020 period and significant reductions in hospital admissions related to acute respiratory symptoms and heart disease.

The monetary benefits from the reduced health damage would be primarily related to a lower incidence of premature mortality. On an annual basis, the benefits are estimated at $77 million during the 2011 to 2020 period. In comparison, the annual cost of the proposed revised AirCare Program is estimated to average about $47 million over the same period of time. (For comparison purposes, continuation of the current program is estimated to provide $30 million in annual health benefits at average annual cost of $45 million.)

Economic impacts of the AirCare Program that have not been quantified include the reduced number of vehicles in operation with visibly smoking exhausts. The program also provides an estimated $35 million per year in revenue for the automotive repair industry. Because a significant number of failing vehicles are retired from service or sold outside of the area instead of being repaired, the program is also estimated to result in at least an additional $21 million per year in new vehicle sales. In addition to reducing emissions, this increase in fleet turnover contributes to increased vehicle safety and fuel economy.

Pending more detailed analysis during Phase 2 of the program review, the preliminary recommendations for program modifications are in three categories: (1) changes that will provide greater emissions reductions, (2) changes that will reduce program cost without a significant loss in benefits, and (3) changes that will provide better information regarding program effectiveness. In order of their significance, the modifications that would provide greater emission reductions are as follows:

1. Implement a check for liquid leaks for any vehicles that have high levels of hydrocarbon emissions detected by the IM147 sampling system;

2. Require all vehicles to be inspected on change of ownership if they are more than two years old;

3. Require taxicabs to be inspected beginning at an age of two years; and

4. Make the IM147 dynamometer test with both fast pass and fast fail algorithms the standard dynamometer test procedure for all model years.

Modifications that would improve the cost-effectiveness of the program are as follows:

5. Keep OBD testing as the primary test for 1998 and newer models, but use the IM147 and gas cap functional test as the "fall back" tests for any vehicles with seeking a conditional pass or with an OBD monitor "not ready;"

6. Apply a repair cost limit of $900 to any 1999 and newer model that can pass an IM147 and gas cap functional test; and

7. Allow biennial inspection frequency for all vehicles that pass an initial test, regardless of vehicle age or model year and require all vehicles that fail an initial test to be tested again in one year.

Finally, a program change that would provide better information regarding the effectiveness of the program (and the potential effectiveness of potential future program changes related to particulate emissions) is the following:

8. Continue using full-duration IM240 tests on a random sample, but start including 1998 and newer vehicles that pass the OBD inspection in the sample and add PM measurement capability to the random IM240 testing.

Table 52 summarizes the preliminary recommended changes.

Table 52
Comparison of the Current AirCare Program with the Conceptual Design for a Revised Program

Program Element	Current	Proposed
Network type	Centralized test-only	Same
Inspection centres / lanes	10 / 32	Same
New model year exemptions	First 7 years	First year for taxis, first 7 years for others
Change of Ownership Testing	n.a.	Require testing upon change of ownership for vehicles >2 years old
Inspection frequency/ exhaust test procedure		
• Pre-1992 models	Annual ASM test	Biennial IM147 for passing vehicles; annual IM147 test for failing vehicles
• 1992-1997 models	Biennial IM240 test	
• 1998 and newer models	Biennial OBD	Biennial OBD for passing vehicles; annual OBD and IM147 test for failing vehicles
Evaporative Emissions Testing	Gas cap functional test on pre-1998 models	Gas cap functional test on pre-1998 models and 1998 and newer models that with OBD evap monitor not ready. Liquid leak test on vehicles with high HC
Cost Limits		
• Pre-1981 models	$300	Same
• 1981-1987 models	$400	Same
• 1988-1991 models	$500	Same
• 1992-1998 models	$600	Same
• 1999 and newer models	No limit	$900 limit for vehicles that are not gross polluters
Random Sample	IM240, except for vehicles passing OBD test	IM240 and PM testing for all vehicles
Fleet testing	At inspection centres	Same
Contract period	5 years	5-7 years, pending more detailed analysis
Test fees	$43 for initial IM240 or OBD test; $23 for initial ASM or idle test or OBD retest	Maximum of $43 for all initial tests and $23 for all retests

As shown in Table 52, our preliminary estimate is that the potential program changes listed above can be accomplished without increasing the current inspection fee for IM240 and OBD testing. The rationale for each of the proposed changes is summarized below.

<u>Liquid Leak Testing</u> – Although the gas cap test currently being used is effective in identifying many vehicles with excessive evaporative emissions, a test for vehicles with liquid leaks would lead to further reductions in HC emissions. Consideration of a test for liquid leaks has been suggested in previous program reviews, but a practical and effective test procedure had not been demonstrated. A simple and effective test now appears to be available. The proposed technique involves using a hydrocarbon "sniffer" to identify vehicles with liquid leaks when the sample being collected by the exhaust sampling systems detects a high hydrocarbon concentration. The reduction in emissions associated with the detection and correction of vehicles with liquid fuel leaks would be especially beneficial in the Lower Fraser Valley because the mixture of pollutants in the atmosphere is such that HC reductions are most beneficial in reducing ozone.

<u>Change of Ownership Testing</u> – One of the significant benefits of I/M programs is that they deter motorists from removing or otherwise tampering with emissions control systems. However, in conjunction with the seven-year exemption for new vehicles, the lack of change of ownership testing makes it possible for the owners of relatively new vehicles to tamper with emissions control systems with virtually no risk of penalty if they intend to sell the vehicle before it is eight years old. The requirement for vehicles to be inspected upon change of ownership would have three benefits. First, it would often require the repair of tampered vehicles sooner. Second, it would serve as a deterrent to tampering in the first place by making owners responsible for the repair of any tampering they might be inclined to do. Third, it provides a measure of consumer protection for the purchasers of used vehicles who subsequently become obligated to correct tampering when the vehicle becomes subject to the AirCare program.

<u>Taxicab Testing</u> – Many emissions-related defects occur in taxicabs during the seven-year exemption period because of the extremely high rate of mileage accumulation typical of taxicab service. Many cabs are essentially worn out before they become subject to testing under the current program. The limited data available on taxicabs tested after seven years indicate that they have extraordinarily high emissions before they become subject to AirCare repair requirements. Based on the available data regarding emissions and mileage accumulation, the new-vehicle exemption for taxicabs should be reduced to one year. At age two, the average cab has already accumulated as many kilometers as the average privately owned vehicle accumulates in eight years.

<u>IM147 Testing</u> – Previous studies have demonstrated that the last 147 seconds of the IM240 dynamometer test are more effective in identifying vehicles with emissions-related defects than the first 93 seconds of the test. The "IM147" test uses only the last 147 seconds of the IM240 test. Replacing the ASM test (currently used for pre-1992 models) and the IM240 test (currently used for 1992-1997; models) with the IM147 test would improve the detection of emissions defects in the pre-1992 models and reduce the time required for testing all vehicles, especially with the use of a fast fail algorithm. The IM147 test also offers the advantage of providing meaningful fuel economy/greenhouse gas estimates for pre-1992 models that are not possible with the ASM test. In addition,

there is a cost savings associated with maintaining only one set of emissions analyzers in each test lane. Subjecting all vehicles to the same exhaust emissions test procedure may also seem more equitable to the general public.

<u>Fall-Back Testing for OBD Vehicles</u> – Under the current program, 1998 and later model vehicles can pass an OBD inspection even if one monitor is “not ready.” Additional emission reductions should be achievable by requiring dynamometer and/or gas cap testing of any vehicle with an OBD monitor that is not ready. Unless the vehicle can pass the dynamometer and/or gas cap test, repairs would be required.

<u>Repair Cost Limit for 1999 and Newer Vehicles</u> – The repair cost limits are the maximum the owner of a failed vehicle is required to spend if the repairs are performed by a certified repair technician working at a certified repair centre. Under the current program, pre-1999 models have repair cost limits ranging from $300 to $600, depending on vehicle age, but there is no repair cost limit for 1999 and newer vehicles. The oldest of the 1999 and newer vehicles has reached the point where some repairs required to pass an OBD test may exceed the value of the vehicle while resulting in relatively little emissions benefit. This is especially a concern with vehicles certified to Low Emission Vehicle or “Tier 2” standards that have experienced a relatively minor loss in catalyst efficiency. To improve the cost-effectiveness of the program and to reduce the economic burden on vehicle owners, it is recommended that a $900 repair cost ceiling be applied to vehicles that have relatively low emissions on an IM147 dynamometer test and can pass a gas cap functional test. Additional repair costs would be required only for vehicles that are gross polluters.

<u>Uniform Requirements for Biennial and Annual Inspections</u> – Under the current program, pre-1992 model vehicles require annual inspections regardless of how clean they were during their previous I/M test. In contrast, newer vehicles require only biennial testing, even when the previous I/M test indicated that they had been poorly maintained. When initially imposed, determining inspection frequency based on model year was reasonable because few 1992 and newer vehicles were old enough to have a high failure rate. Annual inspection frequency was justified for pre-1992 vehicles not only based on their age, but also because they were tested using a less effective exhaust emissions test procedure. In conjunction with a change to IM147 testing, older vehicles should arguably have the same opportunity to avoid annual inspection frequency by proving they were in good repair when initially tested. The minor loss in emissions benefits can be made up by requiring annual testing for 1992 and newer models that fail their initial test.

<u>Expanded IM240 Testing</u> – Subjecting a random sample of vehicles to full-duration IM240 testing provides a valuable source of information regarding the average emissions of the motor vehicle fleet. Under the current program, 1998 and newer vehicles that pass the OBD inspection are exempted from the random sample. This was a reasonable time-saving measure when there were relatively few 1998 and newer models subject to inspection and when it was likely that the IM240 emissions of passing vehicles were very likely close to zero. However, as the fleet ages, 1998 and later model vehicles, especially those with “not ready” OBD monitors, cannot be assumed to be near zero emissions. There is now value in adding them to the random sample.

With increasing emphasis on reducing motor vehicle fuel consumption and greenhouse gas emissions, it is likely that an increasing fraction of the light-duty vehicle fleet will be equipped with Diesel engines. Although emissions standards for new Diesel-powered vehicles require effective control of particulate emissions, the opacity test in the current AirCare program is inadequate for determining the effectiveness of modern Diesels equipped with particulate filters. In addition, the current program is incapable of detecting gasoline vehicles with high particulate emissions unless they are visibly smoking.

There is not sufficient evidence that it would be cost-effective to add a particulate emissions test to the AirCare program. However, because of the growing recognition that particulate emissions are a more important source of air pollution than previously recognized, it would be useful to begin collecting particulate emissions data on a random sample of vehicles. At a minimum, this would improve the accuracy of the vehicle emissions inventory. The testing could be terminated if it is determined that the fraction of the fleet with excessive emissions is too small to be cost-effectively controlled through the implementation of routine inspections. If, however, testing indicates that routine PM testing would identify vehicles with excessive emissions that can be cost-effectively repaired, the feasibility and cost of incorporating routine PM testing can be evaluated.

Phase 2 – If the Steering Committee decides that the emission reductions available through continuation of the AirCare program are desirable, Phase 2 of the project needs to be initiated expeditiously. There is barely sufficient lead time remaining to perform a more detailed evaluation of potential program changes and then to prepare a revised program design in time for prospective service providers to use it to prepare bids for the operation of inspection centres beyond December 31, 2011. High priority tasks to be completed during the Phase 2 study include the following:

1. Develop a detailed analysis of the effect of converting to IM147 testing on lane throughput;

2. Develop proposed emission standards for IM147 testing, including fast-pass and fast-fail standards;

3. Provide a detailed analysis of the changes required to incorporate liquid leak testing for vehicles with high HC emissions detected by the CVS sampling system and develop an estimate of the effect on lane throughput;

4. Develop a detailed protocol for fall-back testing of vehicles with “not ready” OBD systems;

5. Prepare an analysis of the options for requiring taxis to be inspected after one year;

6. Develop a detailed analysis of the changes required to add particulate emissions testing to the random IM240 sample; and

7. Prepare a detailed analysis of the cost associated with continuing operation of the current test facilities vs. constructing a network of new facilities.

Sierra's I/M cost spreadsheet model[76] can be modified as necessary to perform all of the calculations required to estimate testing fees for the revised program for a range of amortization periods. We would also refine the preliminary assessment of the emissions reductions and cost-effectiveness associated with the revised program based on a more detailed review of available data on the occurrence of liquid leaks as a function of vehicle age.

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[76] The model accounts for individual I/M program cost elements (e.g., direct labour, land, buildings, equipment, overhead, etc.) using a methodology patterned after manual I/M cost worksheets developed by U.S. EPA in the late 1970s. Since 1992, the model has been updated and enhanced to support work that Sierra has performed for a variety of clients, including a 2002 project for U.S. EPA and the 2005 Phase 2 study for the AirCare program. The model has been validated against the actual costs of several different I/M program designs, and successfully predicted the significant cost increase resulting from the implementation of loaded mode testing in the California Smog Check program and the cost of various AirCare II program options under previous work for the Greater Vancouver Regional District.

Appendix A
Canadian Federal Exhaust Emissions Standards

As in the U.S., Canada has been imposing federal emission standards for over three decades. Except for a 12-year period covering the 1975 thru 1987 model years, and a brief period for the 1996–1997 model years, Canada generally has imposed (or implemented through Memoranda of Understanding with the Canadian auto manufacturing industry) the same federal standards as applied federally in the U.S. Following the U.S. pattern, Canadian standards have become progressively more stringent over time.

1971–1974 Model Years

For the 1971 through 1974 model years, Canada controlled emissions nationally from new light-duty vehicles and light-duty trucks through regulations adopted by the Ministry of Transport (Transport Canada) under the Motor Vehicle Safety Act. These early standards were based on the EPA standards governing similar vehicles in the U.S. The standards were as shown in Table A-1.

Table A-1
1971–1974 Model Year Standards
(g/mi)[a]

Model Year	**HC**	**CO**	**NOx**
1971	2.2	23	---
1972	3.4	39	---
1973–1974	3.4	39	3.00

[a] 7-Mode test method used for 1971 model year;
CVS-72 method used for 1972–1974 model years.

1975–1987 Model Years

For this period, Canada imposed its own light-duty vehicle and light-duty truck (<6,000 lbs GVWR) emission standards, which were less stringent than comparable U.S. standards. The regulations were embodied in Section 1103 of the Motor Vehicle Safety Regulations. The standards, shown in Table A-2, were set at a level that allowed manufacturers the option of certifying with or without catalytic converters.

Table A-2 1975–1987 Model Years Standards (g/mi, CVS-75 Test)		
HC	**CO**	**NOx**
2	25	3.1

1988–1993 Model Years ("Tier 0")

For the 1988 thru 1993 model years, by means of amendments to Section 1103 adopted in 1986, Canada re-aligned its standards with U.S. EPA "Tier 0" standards, shown in Table A-3 (LDV standards were 50,000 mile durability basis; LDT standards were 120,000 mile durability basis). Light-duty truck applicability was also extended to vehicles >3750 lbs LVWR and <8500 lbs GVWR.

Table A-3
1988–1993 Model Years ("Tier 0")
(g/mi, CVS-75 Test)

Model Years	**HC**		**CO**		**NOx**		**PM**[a]	
	LDV	**LDT**	**LDV**	**LDT**	**LDV**	**LDT**[b]	**LDV**	**LDT**[b]
1988–1993	0.41	0.80	3.4	10	1.00	1.20	0.20	0.26

[a] PM standards apply to Diesel only.
[b] For LDTs over 3,750 lbs LVW, NOx standard was 1.7 g/mi.

Virtually all vehicles certified to these standards used catalytic converters.

1994–1995 Model Years (Partial Implementation of U.S. "Tier 1")

For the 1994–1995 model years, Canada did not adopt more stringent emissions regulations. Instead, in February 1992 Transport Canada entered into a Memorandum of Understanding (MOU) with the Canadian automobile manufacturers under which auto manufacturers agreed to implement U.S. EPA Tier 1 standards for gasoline-fueled 1994 and 1995 model year light duty vehicles (passenger cars) and light-duty trucks <8500 lbs GVWR.

Rather than applying the Tier 1 phase-in schedule applicable under EPA regulations, under the MOU Canadian vehicles were harmonized with U.S standards on a "product" basis, i.e., if a vehicle model manufactured for sale in the U.S. was designed to meet Tier 1 standards, then the same model would be offered for sale in Canada. The practical result was that Tier 1 compliant vehicles were phased-in in Canada, but at a rate different from that in the U.S. due to the different model mix in Canada. The U.S. EPA Tier 1 standards, in g/mi based on the CVS-75 test procedure, are shown in Tables A-4 and A-5.

Table A-4
Tier 1 LDV (PC) Standards

Fuel	Durability Basis	THC	NMHC	CO	NOx	PM
Gasoline	50K	0.41	0.25	3.4	0.4	0.08
	100K	---	0.31	4.2	0.6	0.10
Diesel	50K	0.41	0.25	3.4	1.0	0.08
	100K	---	0.31	4.2	1.25	0.10

Table A-5
Tier 1 LDT Standards

Fuel	Weight Category	Durability Basis	THC	NMHC	CO	NOx	PM
Gasoline	LDT1	50K	---	0.25	3.4	0.4	0.08
		100K	0.80	0.31	4.2	0.6	0.10
	LDT2	50K	---	0.32	4.4	0.7	0.08
		100K	0.80	0.40	5.5	0.97	0.10
	LDT3	50K	---	0.32	4.4	0.7	---
		100K	0.80	0.46	6.4	0.98	0.10
	LDT4	50K	---	0.39	5.0	1.1	---
		100K	0.80	0.56	7.3	1.53	0.12
Diesel	LDT1	50K	---	0.25	3.4	1.0	0.08
		100K	0.80	0.31	4.2	1.25	0.10
	LDT2	50K	---	0.32	4.4	---	0.08
		100K	0.80	0.40	5.5	0.97	0.10
	LDT3	50K	---	0.32	4.4	0.7	---
		120K	0.80	0.46	6.4	0.98	0.10
	LDT4	50K	---	0.39	5.0	1.1	---
		120K	0.80	0.56	7.3	1.53	0.12

1996–1997 Model Years

The 1992 MOU was not extended beyond the 1994–1995 model years, nor did Transport Canada revise its regulations. As a result, the requirements for 1996–1997 model year light-duty vehicles and light trucks reverted back to those applicable during the 1988 to 1993 model years.

1998–2000 Model Years (Full Implementation of U.S. "Tier 1" Standards)

In June of 1997, Transport Canada revised its regulations to uniformly apply U.S. EPA Tier 1 standards to all 1998 and later model year light-duty vehicles (passenger cars) and light-duty trucks < 8500 lbs GVWR. Tier 1 vehicles were also subject to Supplemental Federal Test Procedure (SFTP) requirements, which were standards to control emissions during aggressive driving (SF06 Test Procedure) and while the air conditioning system is operating (SC03 Test Procedure). In order to coordinate with the implementation of the NLEV program in the U.S., the SFTP requirements were delayed one year and did not take effect until the 2001 model year. Tier 1 vehicles were also subject to additional standards for Cold CO (gasoline vehicles only), idle CO (gasoline, methanol, CNG, and LPG LDTs), and the "Certification Short Test" (gasoline vehicles only), which limited emissions to 100 ppm HC and 0.50% CO at idle and 2500 rpm.

2001–2003 Model Years ("NLEV" Standards)

The Tier 1 exhaust emission standards for 1998 and later model year light-duty vehicles and light trucks in the Transport Canada regulations were not revised for the 2001–2003 model years, and remained in place as the official regulatory standards. However, pursuant to a June 2001 Memorandum of Understanding between the Canadian government and Canadian automotive manufacturers, the latter voluntarily certified their vehicles to more stringent National Low Emission Vehicle (NLEV) standards that were mandatory in designated eastern states in the U.S. for the 1999–2000 model years to address higher ozone levels in that area and then applied nationally in the U.S. for the 2001–2003 model years. The NLEV standards, shown in Table A-6 and A-7, were similar to the LEV I standards in effect in California over this period.

In addition, NLEV vehicles had to meet Tier 1 standards at high altitude, and special 50º F emission standards at 4,000 miles (except Diesel, CNG, or hybrid vehicles). Gasoline fueled NLEVs had to meet certification short-test standards: not to exceed 100 ppm HC or 0.50% exhaust gas CO at idle and 2500 rpm at 4,000 miles. Highway NOx could not exceed 1.33 times the applicable FTP NOx certification standard. The full useful life for the THC standards for LDT1s and LDT2s was set at 11 yrs/120,000 miles. Various exceptions and special requirements were applied to alternative-fuel and flex-fuel vehicles. Special provisions applied to small-volume manufacturers.

Table A-6
5 yrs/50,000-mi NLEV Exhaust Emission Standards (FTP-75, g/mi)

Vehicle Type	Emission Category	THC	NMHC	NMOG	CO	NOx	PM	HCHO
LDV	TLEV	0.41	---	0.125	3.4	0.4	0.08	0.015
	LEV	0.41	---	0.075	3.4	0.2	0.08	0.015
	ULEV	0.41	---	0.040	1.7	0.2	0.08	0.008
	ZEV	0.00	0.00	0.000	0.0	0.0	0.00	0.000
LDT1	TLEV	---	---	0.125	3.4	0.4	0.08	0.015
	LEV	---	---	0.075	3.4	0.2	0.08	0.015
	ULEV	---	---	0.040	1.7	0.2	0.08	0.008
	ZEV	0.00	0.00	0.000	0.0	0.0	0.00	0.000
LDT2	TLEV	---	---	0.160	4.4	0.7	0.08	0.018
	LEV	---	---	0.100	4.4	0.4	0.08	0.018
	ULEV	---	---	0.050	2.2	0.4	0.08	0.009
	ZEV	0.00	0.00	0.000	0.0	0.0	0.00	0.000

Table A-7
10 yrs/100,000-mi NLEV Exhaust Emission Standards (FTP-75, g/mi)

Vehicle Type	Emission Category	THC	NMHC	NMOG	CO	NOx	PM	HCHO
LDV	TLEV	---	---	0.156	4.2	0.6	0.08	0.018
	LEV	---	---	0.090	4.2	0.3	0.08	0.018
	ULEV	---	---	0.055	2.1	0.3	0.04	0.011
	ZEV	0.00	0.00	0.000	0.0	0.0	0.00	0.000
LDT1	TLEV	0.80	---	0.156	4.2	0.6	0.08	0.018
	LEV	0.80	---	0.090	4.2	0.3	0.08	0.018
	ULEV	0.80	---	0.055	2.1	0.3	0.04	0.011
	ZEV	0.00	0.00	0.000	0.0	0.0	0.00	0.000
LDT2	TLEV	0.80	---	0.200	5.5	0.9	0.10	0.023
	LEV	0.80	---	0.130	5.5	0.5	0.10	0.023
	ULEV	0.80	---	0.070	2.8	0.5	0.05	0.013
	ZEV	0.00	0.00	0.000	0.0	0.0	0.00	0.000

Under the MOU, Canada did not enforce the NLEV fleet average NMOG standards that applied in the U.S. Instead, manufacturers harmonized on a “product” basis, i.e., if a vehicle model manufactured for sale in the U.S. was designed to meet U.S. fleet average standards, then the same model would be offered for sale in Canada. The U.S. NLEV fleet average NMOG standards are shown in Table A-8 for informational purposes.

Table A-8
NLEV Fleet Average
NMOG Standards (g/mi)

Vehicle Type	2001-2003 Model Years
LDV and LDT1	0.075
LDT2	0.100

Similarly, the NLEV supplemental federal test procedures governing emissions on the more aggressive US06 test procedure and the SC03 test procedure for driving with the A/C system in operation were implemented on a "product" harmonization basis under the MOU, rather than in strict accordance with the phase-in schedule that applied in the U.S.

2004 And Later Model Years ("Tier 2" Standards)

In 1999, passage of the Canadian Environmental Protection Act (CEPA) transferred authority over regulation of motor vehicle emissions from Transport Canada to Environment Canada. After a period of debate to determine whether complete harmonization with the U.S. program was still in the best interests of Canada, the government decided to continue its policy of harmonization, and in 2002 Environment Canada adopted the U.S. EPA Tier 2 standards. This action had the effect, in Canada as in the U.S., of making larger passenger vehicles up to 10,000 lbs GVWR subject to the same standards as smaller passenger cars and light-duty trucks.

The EPA Tier 2 standards for 2004 and later apply to PCs, LDTs up to 8,500 lbs GVWR, and MDPVs up to 10,000 lbs. The LDT category is broken down into the same four weight categories as for the Tier 1 program, with LDT1 and LDT2 together comprising the light light-duty truck (LLDT) category up through 6,000 lbs GVWR, and LDT3 and LDT4 together comprising the heavy light-duty truck (HLDT) category of 6001–8,500 lbs GVWR. Except where noted, the same standards apply regardless of the fuel used. The standards include eight permanent certification levels or "bins" and a fleet average NOx standard of 0.07 g/mi. Three temporary certification bins (9, 10, and an MDPV bin) were available as transition bins in the early years of the program, and expired after the 2006 model year (2008 model year for HLDTs). The Tier 2 standards are set forth in Table A-9.

Table A-9
Tier 2 Exhaust Emission Standards (CVS-75 Test, g/mi)

Bin	50,000-mi Durability Basis					120,000-mi Durability Basis				
	NMOG	CO	NOx	PM	HCHO	NMOG	CO	NOx[g]	PM	HCHO
Temporary Bins										
MDPV[a]	0.195	5.0	0.6	---	0.022	0.280	7.3	0.9	0.12	0.032
10[b,c,d,f]	0.125 (0.160)	3.4 (4.4)	0.4	---	0.015 (0.018)	0.156 (0.230)	4.2 (6.4)	0.6	0.08	0.018 (0.027)
9[b,c,e]	0.075 (0.140)	3.4	0.2	---	0.015	0.090 (0.180)	4.2	0.3	0.06	0.018
Permanent Bins										
8[c]	0.100 (0.125)	3.4	0.14	---	0.015	0.125 (0.156)	4.2	0.20	0.02	0.018
7	0.075	3.4	0.11	---	0.015	0.090	4.2	0.15	0.02	0.018
6	0.075	3.4	0.08	---	0.015	0.090	4.2	0.10	0.01	0.018
5	0.075	3.4	0.05	---	0.015	0.090	4.2	0.07	0.01	0.018
4	---	---	---	---	---	0.070	2.1	0.04	0.01	0.011
3	---	---	---	---	---	0.055	2.1	0.03	0.01	0.011
2	---	---	---	---	---	0.010	2.1	0.02	0.01	0.004
1	---	---	---	---	---	0.000	0.0	0.00	0.00	0.000

[a] Expires after 2008 model year.

[b] Bin deleted at end of 2006 model year (2008 model year for HLDTs).

[c] Higher NMOG, CO, and HCOH values apply only to HLDTs and expire after 2008.

[d] Optional temporary NMOG standards of 0.195 g/mi (50,000 mi) and 0.280 g/mi (120,000 mi) apply only to qualifying LDT4s and MDPVs.

[e] Optional temporary NMOG standards of 0.100 (50,000 mi) and 0.130 g/mi (120,000 mi) apply only to qualifying LDT2s.

[f] 50,000 mi standards optional for Diesels certified to Bin 10.

[g] Manufacturer’s fleet of Tier 2 vehicles must comply with an average of 0.07 g/mi.

The fleet average NOx standard is a particularly important feature of these standards, as it determines how many vehicles in each of the applicable bins may be produced in a given model year.

The U.S. EPA Tier 2 regulations contain a 25/50/75/100% phase-in schedule for PCs and LLDTs over the 2004/05/06/07 and later model years, and 50/100% for HLDTs and MDPVs over the 2008/09 and later model years. All Tier 2 vehicles produced in compliance with the phase-in schedule must meet the 0.07 g/mi NOx fleet average requirement. As shown in Table A-10, in place of the EPA phase-in schedule, Environment Canada adopted fleet average NOx phase-in requirements applicable to two separate categories (LDVs + LLDTs and HLDTs + MDPVs) of a manufacturer’s entire fleet beginning in the 2004 model year.

Table A-10
Canadian Fleet Average NOx Phase-in Requirements (g/mi)

Model Year	2004	2005	2006	2007	2008	2009 & Later
LDVs & LLDTs	0.25	0.19	0.13	0.07	0.07	0.07
HLDTs & MDPVs	0.53	0.43	0.33	0.20	0.14	

Environment Canada considers its fleet average NOx phase-in requirements to be equivalent to the U.S. EPA phase-in schedule.

<u>Tier 2 Supplemental Federal Test Procedures</u> – 2004 and later model year LDVs (PCs) and LDTs fueled by gasoline or Diesel are subject to Supplemental Federal Test Procedure (SFTP) standards during more aggressive driving (US06 test procedure) and while the A/C system is operating (SC03 test procedure). The SFTP standards do not apply to alternative-fueled LDVs and LDTs, flex-fueled LDVs and LDTs when operating on alternative fuel, or MDPVs.

<u>In-Use Standards</u> – Table A-11 shows the in-use standards that apply to 2004–2008 model year LDVs/LLDTs and to HLDTs/MDPVs through the 2010 model years, using commercially available fuels. These standards do not apply to certification, and are the first time that Canada has imposed in-use standards applicable to vehicles driven by the public.

Table A-11
In-Use Certification Standards (g/mi)[b]

Certification Bin No.	Durability Period (mi)	NOx In-Use	NOx Certification[a]	NMOG In-use	NMOG Certification[a]
5	50,000	0.07	0.05	---	0.075
	120,000	0.10	0.07	---	0.090
4	120,000	0.06	0.04	---	0.070
3	120,000	0.05	0.03	0.09	0.055
2	120,000	0.03	0.02	0.02	0.010

[a] Shown for reference only.
[b] Separate standards apply for Diesel vehicles certified to Bin 10 standards.

Following the model years noted above, the Tier 2 standards to which a vehicle is certified become the applicable in-use standards.

Other Standards – Tier 2 vehicles are also subject to Cold CO Standards (applicable only to gasoline-fueled LDV/LDTs and MDPVs), Certification Short Standards (applicable to gasoline-fueled Otto-cycle LDV/LDTs and MDPVs), Highway NOx Standards (except for MDPVs), On-Board Diagnostic system requirements, and evaporative and refueling Emission Standards.

Appendix B
Alternative Technologies and Fuels

Although vehicles and fuels need to be treated as a system, changes in vehicle technology have historically driven changes in fuels. Fuel producers have adapted to changing vehicle technology and emissions control requirements by increasing fuel octane, eliminating lead additives, reducing volatility, reducing sulfur content, and adding detergents and deposit control additives. However, certain alternative fuels require significant changes in vehicle technology. In cases where fuel changes imply other technology changes (e.g., hydrogen and fuel cells), the associated technology changes must also be considered.

Although there is currently some use of alternative fuels, gasoline and Diesel fuel produced from crude oil remain the primary automotive fuels. Because crude oil is a finite resource (the formation rate of new supplies is orders of magnitude slower than the current rate of consumption), greater use of alternative fuels will eventually be required. But a realistic plan for the transition to alternative fuels requires a realistic perspective regarding the future availability of conventional fuels. Forecasts of an impending decline in oil production have been made repeatedly since 1919.[1,2] However, oil exploration and production technology continues to progress and petroleum resources once considered unavailable continue to become economically feasible. As a result, global oil production has continued to expand and can continue expanding at least through 2030,[3] barring governmental restrictions on the development or use of additional resources.

It is fortunate that actual petroleum resources exceed the public perception because conversion to alternative energy resources will take a long time. This problem was pointed out in an article published in Scientific American,[4] which presented time estimates by the Massachusetts Institute of Technology (MIT) for hydrogen fuel cell vehicles:

Time before becoming competitive in the market: ≈15 years
Time for penetration across new vehicle production: ≈25 years
Time for major fleet penetration: ≈20 years
Total time required for maximum effect: ≈55 years

Although the petroleum supply is currently adequate to meet world needs for years to come, a more rapid transition to alternatives may be necessary to the extent that government policies or geopolitical events restrict the use of petroleum. In the U.S., for example, the substitution of alternative fuels for petroleum-based fuels has been

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[1] R. W. Ferrier, and J. H. Bamberg, "The History of the British Petroleum Company," Cambridge University Press, 1982.

[2] D. Yergin, "The Prize: The Epic Quest for Oil, Money, and Power," (Simon & Schuster, New York, 1991), p. 194.

[3] "International Energy Outlook 2008," Energy Information Administration Report Number DOE/EIA-0484(2008), September 2008.

[4] John B. Heywood, "Fueling Our Transportation Future," Scientific American, September 2006.

promoted as a means to reduce dependence on foreign energy sources and to reduce greenhouse gas (GHG) emissions. However, it should be stressed that alternative fuel use will not necessarily lower GHG emissions. The actual impact of any alternative fuel on GHG emissions depends on the GHG emissions associated with the process used to produce it and, in the case of so-called “biofuels,” the GHG emissions associated with changes in land use required to grow the crops used as feedstocks for the fuel.

The model maintained by Natural Resources Canada (NRCan) to assess GHG impacts of alternative fuels is called “GH-Genius.” Based on our review of the model in 2007, it assumes existing farmland is used for energy crops like soybeans grown for use in biodiesel production. Given the growing demand for food and animal feed, this is not a reasonable assumption. Even if food crops grown in Canada are replaced with energy crops, the demand for the displaced food crops still exists and must be filled somewhere. The net effect is that the total amount of land in agricultural production must increase.

In addition to ignoring the impact of more land being brought into agricultural production when biofuel crops are grown, the GHGenius model uses values for the “global warming potential” (GWP) of various emissions published by the United Nations Intergovernmental Panel on Climate Change (IPCC). The GWP for certain compounds is not included and, in some cases, there are better estimates available than published by IPCC. The Lifecycle Emissions Model (LEM), developed by Dr. Mark Delucchi from the University of California, Davis, is the model from which GHGenius was originally developed. The current version of LEM provides an alternative source of estimates that better represent the net effect of growing more energy crops in the future by assuming that additional land is brought into production.

Because of the differences in the models, GHGenius estimates much greater emission-reduction benefits with biofuels than does the LEM. The main reason for this difference is that the LEM estimates very large N_2O emissions from nitrogen fixation and large releases of soil and plant carbon from land use changes resulting from additional land being brought into agricultural production.

Notwithstanding the uncertainties described above, the potential advantages of alternative fuels are summarized in Table B-1. Internal combustion engines can be modified to use any of the gaseous or liquid fuels listed in the table. Fewer engine modifications are sometimes required if the alternative fuel is blended with a conventional fuel, like gasoline. The advantages and disadvantages associated with each of these fuels are discussed below.

Table B-1
Potential Advantages Of Alternative Transportation Fuels

Fuel	Potential Advantages
Electricity	Zero vehicle emissions Available from renewable sources or alternative fossil fuels Lower GHG emissions if from renewables or nuclear
Ethanol	Lower GHG emissions Available from biomass
Natural Gas	Lower GHG emissions
LPG	Lower GHG emissions
Methanol	Available from biomass or alternative fossil fuels Lower GHG emissions if from biomass
Hydrogen	Low or Zero vehicle emissions Available from renewable sources or alternative fossil fuels Lower GHG emissions if from renewables or nuclear Lower GHG emissions if from natural gas and used in a fuel cell
Biodiesel	Lower GHG emissions Available from biomass
"Clean Diesel"	Lower GHG emissions
Fischer-Tropsch Gas/Diesel	Available from biomass or alternative fossil fuels

Electricity – Electric vehicles have been commercially produced for over 100 years. Although they have been successful in niche applications, the high weight and cost of batteries are substantial constraints to the expanded use of battery-electric vehicles. The evolution of electric vehicle technology is increasing the potential for electricity to displace conventional fuels; however, technological breakthroughs that would significantly reduce battery weight and cost will be required for electricity to make major inroads.

Energy Efficiency – Literature references to the high-energy efficiency of electric vehicles invariably ignore the efficiency with which electricity is produced from fossil fuel. Electric vehicles use less energy than comparably sized gasoline-fueled vehicles only when the energy used to recharge the battery is measured at the wall outlet. Considering the entire fuel cycle, the energy efficiency of electric vehicles is comparable to that of conventional gasoline vehicles.[5] (Electric vehicles are able to use non-fossil forms of energy, but marginal electricity demand is provided by the combustion of fossil fuel.)

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[5] T.C. Austin and L.S. Caretto, "Powerplant Emissions and Energy Consumption Associated with Electric Vehicle Recharging," 5th Coordinating Research Council On Road Vehicle Emissions Workshop, April 3, 1995.

Cost – There are two elements of cost that must be considered when addressing electric vehicles: electricity cost and vehicle cost. Electricity can be produced from hydro, nuclear, and fossil resources at costs that compare favorably with current gasoline prices. However, the cost of electricity from solar energy remains problematic. Even in the U.S., where average solar intensity is higher, the Department of Energy summarizes the cost of solar electric power as follows:

> *Concentrating solar power technologies currently offer the lowest-cost solar electricity for large-scale power generation (10 megawatt-electric and above). Current technologies cost $2–$3 per watt. This results in a cost of solar power of 9¢–12¢ per kilowatt-hour.*[6]

This compares to a wholesale cost of less than US$0.05 per kWh for fossil, nuclear, and hydro generation. Electricity produced by photovoltaic (PV) systems is even more expensive. The most economical, large-scale systems have costs of approximately US$0.20 per kWh when installed in sunny climates.[7]

As noted above, the cost of solar electric systems depends on the climate. The estimates of solar electric cost based on studies funded by U.S. Department of Energy (DOE) are routinely based on conditions that exist in the Southwestern U.S., where annual average solar intensity is in the range of 7 kWh per day. Due to differences in cloud cover and latitude, average solar intensity in Canada is about half the level of the Southwestern U.S. Since the infrastructure costs would be equivalent, the most economical form of solar electricity in Canada would be several times the cost of producing electricity from other sources. As a result, the large-scale production of electricity from solar energy is not feasible in Canada at the current time. Obviously, the subsequent production of hydrogen from solar electricity is also infeasible. The ultimate potential of electricity from solar power in Canada depends on breakthroughs in PV technology.

Vehicle cost is a significant factor with respect to electric vehicles. When California adopted its Zero Emission Vehicle Mandate in 1990, it projected that rapid progress in electric vehicle technology would reduce the cost premium for full-function electric vehicles to US$1,350 by model year 2003. As is often the case, forecasts of rapid reductions in technology cost do not actually occur. Based on a 2003 evaluation sponsored by the California Air Resources Board, the cost of a battery for a full-function electric vehicle would be US$9,000 to US$11,000 in mass production (hundreds of thousands per year).[8] Using a markup factor of 1.6 to the retail level[9, 10] and assuming no

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[6] "CSP Technologies Overview," Sandia National Laboratories, available at http://www.energylan.sandia.gov/sunlab/overview.htm#techover

[7] "Solar Electric Global Benchmark Price Indices," Solarbuzz LLC, May 2006.

[8] http://www.arb.ca.gov/msprog/zevprog/2003rule/03board/anderman.ppt

[9] A. Vyas, D. Santini, and R. Cuenca, "Comparison Of Indirect Cost Multipliers For Vehicle Manufacturing," Center for Transportation Research, Energy Systems Division, Argonne National Laboratory, April 2000.

[10] The referenced Argonne National Laboratory report on cost multipliers concludes that 1.5 is an appropriate multiplier to translate the price of a vendor-developed component to Retail Price Equivalent in the case that the vendor takes responsibility for all warranty costs. The 1.6 multiplier is based on the more typical case where the vehicle manufacturer ends up taking responsibility for the majority of warranty

other net cost increase for a full-function electric vehicle, the increase in retail vehicle price would be approximately US$16,000.[11] The combination of the price premium for electric vehicles combined with their limited driving range makes them commercially infeasible for anything other than niche markets.

Plug-in Hybrid Vehicles – To minimize the size and cost of the battery required for a pure electric vehicle, it is possible to use a hybrid vehicle using grid power only for short trips. Unlike hybrid vehicles already in mass production (e.g., Toyota Prius), so-called "grid-connected hybrid electric vehicles" or "plug-in hybrid electric vehicles" (PHEVs), such as General Motors' Chevrolet Volt, recharge their batteries from the electrical grid rather than from their combustion engine. This gives the vehicle some "all-electric range" and allows the vehicles to be driven without the use of gasoline to the extent that their batteries are recharged from the electrical grid and the distance they are driven between recharging is equal to or less than their "all electric range" (i.e., the driving range available from the battery). (Beyond the all-electric range, the combustion engine is used.)

The battery size required for a PHEV with a 20-mile all electric range, calculated from the energy per km required to propel a compact size vehicle, is 7 kWh. The retail price increase needed to cover the cost of the battery alone would be approximately US$6,000. Combined with a 100 kW motor/generator, inverter, brake-by-wire, electric power steering, electric accessory drive, high-voltage wiring system, and weight reduction measures to offset the weight increase, the total retail price increase to cover the cost would be approximately US$12,500.[12] This is roughly twice the cost increase associated with a conventional hybrid vehicle that is not grid-connected and has no significant all-electric range, which limits the potential market penetration.

Despite the extremely high price premium, some have claimed that PHEVs would provide economic benefits to motorists because they can be used to store electrical energy and sell it back to the utilities during periods of peak demand. However, analyses of this concept have failed to account for the cost of reducing battery life by exposing it to additional charge/discharge cycles. The projected retail cost of NiMH batteries is approximately US$700/kW-hr. Currently available technology appears to have a life of approximately 1,000 cycles. This means that a profit of US$0.70/kW-hr is necessary just to cover the cost of cycling the battery to sell power back to the grid. Assuming motorists can purchase off-peak power at US$0.06/kW-hr (a representative price for off-

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claims. It should be noted that manufacturer profit is only a minor component of this multiplier. The multiplier must also cover the cost of integrating vendor-developed components into the vehicle.

[11] This price is based on the use of a nickel metal hydride (NiMH) battery, which is assumed to last the life of the vehicle. Although lead-acid batteries would be cheaper, they would need to be replaced more than once during the life of the vehicle, leading to a higher lifetime cost.

[12] Variable costs of the required components are estimated at $3,610 for the battery, $1,225 for a 288v motor/generator, $1,750 for the inverter, $500 for the brakes, $40 for the electric power steering, $70 for the electric accessory drive, $300 for the high-voltage wiring, and $265 for weight reduction measures. Assuming vendors bear all of the R&D and tooling expense, battery, motor/generator, and inverter costs are multiplied by 1.61 to estimate retail price equivalent. Other costs are multiplied by 2.0 (to account for research, development, engineering, and tooling costs of components that are not developed by vendors).

peak power) and sell it back at US$0.18/kW-hr (a representative price for peak power),[13] the profit, ignoring the shortened life of the battery, would be only US$0.12/ kWh. When reduced battery life is accounted for, there is a net loss of US$0.58/kW-hr. This calculation ignores the effect of charging/discharging efficiency, which would further increase the cost. In addition to the fact that resale to the grid makes no economic sense, the fact that the periods of peak electricity demand coincide with peak commute periods means that vehicles will be unavailable to sell power back to the grid.

Emissions – In theory, common air contaminant (CAC) and GHG emissions from electric vehicles can be eliminated if the electricity is produced from wind, hydro, solar, geothermal, or nuclear power. GHG emissions can also be substantially reduced if the electricity is produced from biomass. However, there is an insignificant reduction in GHG emissions if the electricity used to recharge an electric vehicle comes from coal-fired powerplants and emissions of ozone precursors (HC and NOx) are actually higher. This is significant because, at the margin, additional demand for electricity is provided by fossil fuels. Non-fossil resources like nuclear provide base load power.

The net emissions effect of using electricity produced from coal can be explained as follows. By replacing one litre of gasoline with electricity, CO_2 emissions are reduced by 2.3 kilograms (the amount of CO_2 formed by the combustion of one litre of gasoline). Using 0.21 kWh per km as the typical electric power requirement for a compact electric car, it takes 2.44 kilowatt-hours (kWh) to propel an electric vehicle the same distance as a conventional vehicle is propelled by one litre of gasoline (assuming 8.6 l/100 km). To produce 2.44 kWh of electricity, a coal-fired powerplant emits 2.3 kilograms of CO_2,[14] which is exactly equal to the CO_2 emitted by burning a litre of gasoline. The reason that the GHGenius model shows a slight benefit for electric vehicles is that it accounts for the GHG emissions associated with the production of the gasoline in addition to the emissions from the combustion of the gasoline.

With late model vehicles achieving near zero emissions, the CAC emissions associated with electric vehicles are higher if the electricity is generated from fossil fuel fired powerplants unless the electricity is produced in a very efficient gas-fired powerplant equipped with a selective catalytic reduction (SCR) system for the control of NOx emissions.[15]

The energy efficiency, cost, and emissions issues described above do not account for the operation of electric vehicles under the temperature conditions that exist in Canada

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[13] These are the average (summer/winter) rates for time-of-use pricing currently provided by Pacific Gas and Electric (see http://www.pge.com/about_us/environment/electric_vehicles/#topic5).

[14] W. Barbour, et al, "Carbon Dioxide Emissions from the Generation of Electric Power in the United States," U.S. Department of Energy and U.S. Environmental Protection Agency, July 2000.

[15] Although the HC and CO emissions associated with electricity production in fossil fuel-fired powerplants are very low, NOx emissions are significant, even from modern, combined cycle gas-fired turbines. Without SCR, the NOx concentrations from a combined cycle gas turbine power plant may be 25 ppm (corrected to 15% exhaust oxygen), depending on the turbine model and the jurisdiction where the plant was located. Based on an efficiency of 56.5% (LHV basis), this translates into NOx levels of 0.281 grams/kWh. Accounting for distribution and transmission losses, the NOx emissions are 0.30 g/kWh at the wall outlet. For an electric vehicle using 0.21 kWh/km, the NOx emissions would be 0.06 g/km, which is approximately double the emissions associated with a passenger car meeting Tier 2 standards.

during the winter. Automobiles require cabin heaters and defrosters during cold weather. Vehicles using internal combustion engines have a free supply of waste heat available from the cooling system of the engine. In an electric vehicle, the necessary heat has to be generated by a supplemental fuel-fired heater or by using more battery energy to provide resistance heating. Either approach increases energy use and leads to increased GHG emissions to the extent fossil fuels are providing some or all of the energy. A more practical problem associated with the use of electric vehicles in cold weather is that the amount of energy that can be extracted from the battery is diminished. These are both significant problems that are not addressed in the GHGenius model.

Ethanol – Ethanol has been promoted as an alternative to gasoline for over 30 years based on claims of reduced air pollution and oil demand. It is primarily blended into conventional gasoline at 5.7 to 10 percent by volume. There is limited use of 85 percent denatured ethanol/15 percent gasoline blends (called E85).

Ethanol can be produced in a variety of ways from a variety of feedstocks. For industrial use, it can be produced from petroleum feedstock through the acid-catalyzed hydration of ethylene. As an alternative fuel, it is currently produced from the fermentation of sugars or starches. Although not yet commercial, ethanol can also be produced from the fermentation or gasification of cellulose.

Energy Efficiency – There are relatively minor differences in the various estimates of the energy required to produce conventional gasoline. From the well head to the gasoline dispenser, approximately 0.20 British Thermal Units (BTUs) of energy are required to produce gasoline containing 1.0 BTU, yielding an "output/input ratio" of 5.0,[16, 17] which reflects a strongly positive "energy balance."[18] (Significantly more energy is required to produce gasoline from oil sands, coal, shale, and any crude oil heavy enough to require thermally enhanced oil recovery techniques.)

In contrast to the relatively consistent estimates of the energy required to produce conventional gasoline, there are large variations in the estimated energy output/input ratio for ethanol produced from corn, which is currently the primary source of ethanol in the U.S. Based on a 2002 paper by Graboski,[19, 20] the industry average energy output/input ratio for ethanol in calendar year 2000 was 1.11, and perhaps as low as 1.04. For new

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[16] M. Wang, "GREET 1.5 – Transportation Fuel-Cycle Model, Volume 1: Methodology, Development, Use and Results," Center for Transportation Research, Energy Systems Division, Argonne National Laboratory, 1999.

[17] M. Wang, et al., "Allocation of Energy Use in Petroleum Refineries to Petroleum Products Implications for Life-Cycle Energy Use and Emission Inventory of Petroleum Transportation Fuels," Center for Transportation Research, Energy Systems Division, Argonne National Laboratory, 2003.

[18] Instead of comparing the energy in the fuel to the energy required to manufacture the fuel, some analysts count the energy in crude oil feedstock used to produce gasoline as an energy use. Instead of reporting gasoline as having a positive output/input ratio of 5:1, it is reported as having an energy loss of 20 percent. In contrast, ethanol produced with an output/input ratio of 1.2 is reported as having an energy gain of 20 percent. Using this approach, ethanol looks more favorable because the solar energy used to grow the corn is ignored, but the energy content of the crude oil (which was also derived from solar energy) is counted.

[19] M. S. Graboski, "Fossil Energy Use in the Manufacture of Corn Ethanol," Colorado School of Mines, August 2002.

[20] Graboski's estimates have been adjusted to better reflect the energy used to produce seed corn, nitrogen fertilizer, and capital equipment, and to account for the omission of "non-fossil" energy.

plants, Graboski's analysis indicates an output/input ratio of 1.19. However, there is additional energy use associated with ethanol that is not included in these ratios.

Although some energy associated with the production and maintenance of capital equipment has been accounted for in the adjustments made to Graboski's analysis, the adjustments do not account for the additional trucks, rail cars, and barges necessary to move ethanol to market. For vehicles that use ethanol fuel, the loss in fuel economy associated with adding ethanol to gasoline has been accounted for by doing the analysis in terms of BTUs of energy used to produce a BTU of fuel, but that does not address the inefficiency associated with the need for more frequent refueling events. It also does not account for increased evaporative emissions caused by increased permeation losses when gasoline contains ethanol. It is therefore likely that the actual output/input ratio for ethanol is closer to 1.0.[21]

The above-described findings are consistent with the results of a study for NRCan that contained the following conclusion:

> *Wheat, canola, or corn should not be used as energy crops, as they require considerable energy inputs in the form of fertilizer etc., take up prime farmland, and deliver small yields per hectare. Switchgrass or wood from short-rotation forestry (e.g., poplar or willow) should be used to produce energy. This brings into question current thinking in both Canada and the U.S., where corn and wheat are increasingly promoted as ethanol feedstocks.*[22]

Regardless of the output/input ratio, studies routinely conclude that ethanol production significantly reduces the amount of crude oil required per BTU of transportation fuel because coal, natural gas, and other non-oil derived fuels are used in its production. It should be noted, however, that natural gas and coal used in the production of ethanol can also be converted to liquid fuels for transportation. The cost of producing liquid fuels from natural gas and coal directly is potentially more economical than the production of ethanol from grains.

Cost – Because the production of ethanol from corn is an energy-intensive and a labor-intensive process, ethanol prices are higher than gasoline prices on an energy equivalent

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[21] To the extent that fertilizer manufacturing in Canada is more efficient, and to the extent that there is greater use of manure for fertilizer in Canada, the energy balance numbers would be somewhat more favorable for ethanol production in Canada. However, Canada is already an importer of corn (see Corn Refiners Association Annual Report 2006). To the extent that more corn is used for ethanol production, the marginal energy use associated with additional corn production will be controlled by the energy use associated with growing corn in the U.S. It should also be noted that the energy balance is dependent on the credits assigned to byproducts, such as Distiller's Dried Grains (DDG). Significantly increased production of ethanol from corn would require reanalysis of byproduct credits should the market for byproducts become saturated.

[22] Martin Tampier, et al., "Identifying Environmentally Preferable Uses for Biomass Resources, Stage 2 Report: Life-Cycle GHG Emission Reduction Benefits of Selected Feedstock-to-Product Threads," Envirochem Services, Inc., July 19, 2004.

basis.[23] It is generally recognized that the economic viability of ethanol from grains will continue to depend on government mandates and/or subsidies unless long-hoped-for breakthroughs occur in the cost of producing ethanol from cellulose.

Ethanol produced from cellulose (“cellulosic ethanol”) has the potential to cost less because of the lower cost of growing cellulosic feedstocks, such as grasses and trees. However, breakthroughs in the enzymatic decomposition of the cellulose are necessary if ethanol produced from cellulose is going to be cost-competitive without subsidies. Based on a recent study, the cost of cellulosic ethanol using current technology is US$5.15 per gasoline equivalent gallon.[24]

Emissions – Claims of emissions benefits for ethanol-gasoline blends stem from the fact that pre-1980 technology vehicles experience enleanment of the air-fuel ratio when ethanol is added to the fuel. Depending on the particular vehicle, this could result in lower emissions of HC and CO. However, net emissions benefits no longer exist with the highly efficient emission control systems on late model vehicles that incorporate computer control of air-fuel ratio. Although there is still a small CO emissions reduction, CO contributes only weakly to ozone formation, as was discussed above, and ambient CO levels have dropped to the point that further CO control is not required to reduce human exposure. In its 2007 analysis of the Renewable Fuel Standard, EPA concluded “…those areas that experience a substantial increase in ethanol may see an increase in VOC emissions between 4 and 5 percent and an increase in NOx emissions between 6 and 7 percent from gasoline powered vehicles and equipment.”[25]

In addition to the increase in NOx exhaust emissions, the use of ethanol-gasoline blends causes an increase in evaporative emissions, especially in vehicles equipped with plastic fuel tanks. The addition of ethanol to the fuel increases the permeation of fuel through the walls of plastic fuel tanks and through gasoline lines. In new vehicles, this increase is being minimized through the use of revised materials.

Claims of lower GHG emissions for ethanol superficially appear reasonable since the fuel is produced from a crop that absorbs carbon dioxide while growing. However, because the production of ethanol from corn is such an energy-intensive process, there are significant GHG emissions associated with its use. Estimating net differences in GHG emissions requires a detailed analysis that accounts for all GHG emissions associated with each fuel. The analysis is much more complex for biofuels than for conventional fossil fuels because it must account for the emissions associated with the use of the land to grow energy crops instead of the previous land use. The models used to perform such calculations usually assume no new farmland is used for energy crops like soybeans grown for use in biodiesel production. Given the growing demand for food and animal feed, this is not a reasonable assumption. Even if food crops are replaced with energy

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[23] “Annual Energy Outlook 2008,” U.S. Energy Information Administration, Report No. DOE/EIA-0383, June 2008.

[24] D. Hsu, “Techno-economic comparison of biochemical, gasification, and pyrolysis conversion of corn stover to biofuels,” National Renewable Energy Laboratory, March 20, 2009.

[25] “EPA Finalizes Regulations for a Renewable Fuel Standard (RFS) Program for 2007 and Beyond,” Fact Sheet No. EPA420-F-07-019, U.S. Environmental Protection Agency, Office of Transportation and Air Quality, April 2007.

crops, the demand for the displaced food crops still exists and must be filled somewhere. The net effect is that the total amount of land in agricultural production must increase.

Natural Gas – Natural gas has been used as a vehicle fuel for many years, usually being carried on-board a vehicle in high pressure (3,600 psi) cylinders. To minimize the cost, size, and weight of compressed natural gas (CNG) cylinders, liquefied natural gas (LNG) can also be used. LNG is much less popular because of the cost of the cryogenic system and the safety risks associated with venting the tank when the vehicle is parked for extended periods of time. (Even for vehicles that are routinely driven five to seven days per week, it is only a matter of time before a significant number of vehicles end up being parked in an enclosed garage for an extended period of time. Venting of a combustible mixture into an enclosed garage creates an obvious fire/explosion safety risk.)

Energy Efficiency – Natural gas requires relatively little energy to produce, clean, and transport via pipeline. However, there can be significant energy loss associated with the liquefaction process if the gas is cooled to a liquid form (LNG) to reduce its volume. Liquefying natural gas prior to shipment is economically feasible only when there is no pipeline alternative for bringing remote, usually inexpensive, gas to market.

Cost – Although prices fluctuate based on supply and demand, the price of natural gas per BTU has historically been lower than the cost of oil. During supply disruptions, prices can vary significantly. Vehicle cost is higher because of the cost of high-pressure gas cylinders, estimated to be approximately $2,000 for a typical passenger car or light-duty truck in mass production.[26]

There are additional infrastructure costs associated with natural gas because some areas of the country are not served by gas pipelines and high pressure dispensers would need to be installed at refueling facilities.

Emissions – Natural gas has long been recognized as a fuel that produces relatively low emissions compared to gasoline or Diesel fuel. However, the emissions advantage of natural gas has been completely eliminated with modern-day emissions control systems. Both CNG and gasoline-fueled vehicles now have near-zero emissions when equipped with highly effective catalytic converters. GHG emissions from natural gas are 25 percent lower.

LPG – Liquefied Petroleum Gas, which is primarily propane, is a by-product of natural gas and oil refining that has been used as a motor vehicle fuel since the 1920s. Although a gas at standard conditions, LPG can be liquefied under modest pressure, which allows for it to be stored in cylinders that are much less expensive than those required for natural gas. Relatively simple fuel system modifications are necessary to convert a gasoline vehicle to operation on propane.

Energy Efficiency – As a by-product of natural gas production and oil refining, LPG has relatively low production cost. It is simply separated from other molecules using a

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[26] T.C. Austin, et al., “Alternative and Future Technologies for Reducing Greenhouse Gas Emissions from Road Vehicles,” Sierra Research Report No. SR99-07-01, prepared for the Transportation Table Subgroup on Road Vehicle Technology and Fuels, July 1999.

distillation process. However, this “natural” source of LPG is limited. Additional supplies of LNG could be produced by cracking longer chain hydrocarbons, but this would increase the energy used to produce the fuel and increase its cost. LPG burns in internal combustion engines with approximately the same efficiency as gasoline, so there is no compelling reason to produce additional amounts of LPG from crude oil at the expense of additional refinery energy use.

Cost – As a by-product of natural gas production and oil refining, the cost of LPG is significantly affected by local market conditions. Historically, it has been available at a lower price than gasoline, which induces some owners to invest in retrofit systems to allow the use of LPG in a vehicle originally designed for gasoline. As noted above, higher LPG production volumes could be achieved at additional cost.

Emissions – Like natural gas, propane offers inherent advantages over gasoline related to cold starting and low emissions of toxic air contaminants. These advantages are essentially eliminated with the highly effective emissions control systems used on late model vehicles. Based on GHGenius, LPG vehicles emit 24% lower GHG emissions than gasoline-fueled vehicles. Based on LEM, GHG emissions from natural gas are 23% lower.

For the reasons described above, it is unlikely that LPG will ever play a greater role as an alternative fuel than it does currently.

<u>Methanol</u> – Intense interest developed in replacing gasoline with methanol in the 1980s, but advances in gasoline vehicle emissions control technology eliminated the lower emissions previously exhibited by prototype vehicles burning methanol.

Energy Efficiency – Because of its relatively high octane level, methanol allows a slight increase in compression ratio that enables spark ignition engines to achieve somewhat higher efficiency on methanol than on gasoline. However, the production of methanol from natural gas involves efficiency losses that cause it to cost more than natural gas. It is therefore primarily of interest as an alternative transportation fuel if it is made from coal or biomass. In this case, the energy efficiency is less important because of the lower cost and greater availability of the feedstock.

Cost – Adjusting to account for changes in the Consumer Price Index (CPI) since the estimates were made, the production of methanol from wood has been estimated at US$20 per giga-joule (GJ) in a study by researchers at Princeton University.[27] An earlier study by the National Research Council reached almost exactly the same conclusion.[28] On an energy basis, this is equivalent to oil at US$122 per barrel. (These cost estimates explain why natural gas remains the source of virtually all current methanol

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[27] R. H. Williams, et al., “Methanol and Hydrogen from Biomass for Transportation,” Center for Energy and Environmental Studies, School of Engineering and Applied Science, Princeton University, 1995.

[28] “Fuels to Drive Our Future,” Committee on Production Technologies for Liquid Transportation Fuels, Energy Engineering Board, Commission on Engineering and Technical Systems, National Research Council, 1990.

production.[29]) If made from coal, methanol may be cost competitive with gasoline at current oil prices. Two separate references estimate the price of methanol produced from coal to be equivalent to oil at US$50-60 per bbl.[30, 31] Increased vehicle costs for methanol are relatively minor.

As in the case of ethanol, additional infrastructure costs will be associated with a transition to methanol because methanol is not compatible with the existing pipeline infrastructure used for gasoline and Diesel fuel.

Emissions – As discussed above, methanol offers no particular advantage over gasoline with respect to emissions control. Based on lifecycle emissions models, vehicles using "M85" (85 percent methanol/15 percent gasoline) emit significantly lower GHG emissions than gasoline-fueled vehicles if the methanol is made from biomass. However, there is less than a 10 percent benefit in GHG emissions if the feedstock is natural gas.[32]

<u>Hydrogen</u> – Hydrogen has long been viewed as a potential future fuel because of the fact that it can be manufactured by the electrolysis of water using electricity produced from renewable sources (e.g., wind) or nuclear power. Hydrogen can be burned in conventional Otto cycle engines provided the fuel system is modified to be compatible with the fuel. Hydrogen is also the fuel required for proton exchange membrane (PEM) fuel cells that offer the potential for zero emissions of CACs and CO_2. Hydrogen produces no CO_2 when it is either burned in an engine or used in a fuel cell because the products of hydrogen combustion in air or use in a fuel cell are only nitrogen and water vapor. However, the real effect of hydrogen fuel on greenhouse gases depends on the source of the hydrogen. Because hydrogen is not a natural resource like natural gas or crude oil, it has to be manufactured. There can be significant greenhouse gas emissions associated with the production of hydrogen.

Energy Efficiency – Although hydrogen is the most abundant element in the universe, it exists on Earth in a form that is not usable as a fuel. Because of the inefficiencies involved in chemical processes, it takes more than one BTU of energy from some other source to produce one BTU of hydrogen. This is a major issue affecting the economic feasibility of hydrogen. It also creates a strong incentive for producing hydrogen from renewable resources to avoid accelerating the depletion of non-renewable resources.

With natural gas as the feedstock, the overall conversion efficiency, including compression losses, is 72 percent.[33] Therefore, unless there is a commercially feasible vehicle available that can use hydrogen with much higher efficiency than natural gas

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[29] Fuel-grade methanol produced from natural gas was not specifically addressed because of the obvious energy inefficiency and higher GHG emissions associated with this source.

[30] "Fuels to Drive Our Future," Committee on Production Technologies for Liquid Transportation Fuels, Energy Engineering Board, Commission on Engineering and Technical Systems, National Research Council, 1990.

[31] E. D. Larson and R. Tingjin, "Synthetic fuel production by indirect coal liquefaction," Energy for Sustainable Development, Volume VII, No. 4, December 2003.

[32] Results based on the Lifecycle Emissions Model (LEM) developed by Dr. Mark Delucchi, University of California, Davis, 2006.

[33] "The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs," Committee on Alternatives and Strategies for Future Hydrogen Production and Use, National Research Council, 2004.

(which there isn't), converting the gas to hydrogen doesn't make sense from an energy perspective.

Producing hydrogen through the electrolysis of water is a 75 percent efficient process. That means that each kWh of electricity will produce 2559 BTU (3412*0.75) of hydrogen. Because of its low energy density, hydrogen must either be liquefied or compressed for use in motor vehicles. Accounting for the inefficiency associated with compression, the net efficiency of the electrolysis route drops to under 70 percent. Since the thermal efficiency of converting fossil fuels to electricity is no more than about 50 percent in the most modern powerplants, the electrolysis route is not energy efficient if the original energy source is fossil fuel.

Cost – The National Research Council has estimated the all-inclusive cost of hydrogen produced with current electrolysis technology at US$6.56 per kilogram.[34] On an energy basis, that's equivalent to oil at US$330 per barrel.

The principal non-fossil-fuel-based processes for producing hydrogen or other alternative fuels without a net increase in carbon dioxide are the gasification of biomass and the electrolysis of water using electricity produced without fossil fuels. Although some studies claim that hydrogen or other alternatives can eventually be produced economically from such sources, steam methane reforming of natural gas is currently the least expensive source of hydrogen and even that source is relatively expensive. As concluded by researchers at Argonne National Laboratory (ANL), "With current technologies, on a well-to-tank basis, the unit cost of hydrogen is likely to be 2-3 times that of gasoline."[35] This price projection is due in part to the enormous capital investment that will be required to create a hydrogen refueling infrastructure, which ANL estimates will cost over US$600 billion to serve 40 percent of the light-duty vehicle fleet.

Although the prospects for long-term economic viability of hydrogen are questionable, the short-term prospects are more certain. Barring massive subsidies or government mandates, there appears to be no chance that hydrogen will become a commercial success in the next 10 to 20 years. The fundamental problem is the extraordinary level of capital investment required to establish a production, distribution, and refueling infrastructure. To minimize the "hurdle" costs, the initial hydrogen production, distribution, and marketing approach would probably have to involve "decentralized" facilities.

Because of its high fuel cost, the economic feasibility of hydrogen may depend on the successful development of fuel cell vehicles that can achieve substantially higher efficiency than vehicles with internal combustion engines. However, with current manufacturing technology, there is a cost premium for fuel cell vehicles in mass production. Even if significant cost reductions are achieved in the future, it is not clear that fuel cell vehicles will ever be cost competitive with conventional gasoline-fueled vehicles.

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[34] "The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs," Committee on Alternatives and Strategies for Future Hydrogen Production and Use, National Research Council, 2004.

[35] M. Mintz, et al., "Infrastructure Requirements of Advanced Vehicles Using Natural-Gas-Based Fuels," Argonne National Laboratory, Transportation Technology R&D Center, March 12, 2002.

Emissions – Although it is theoretically possible to produce hydrogen without a net increase in carbon dioxide emissions, the cost of doing so is prohibitive. Using the most economic hydrogen production method (steam methane reforming), significant carbon dioxide emissions are generated. Based on GHGenius, hydrogen used in combustion engines produces 2.6% lower GHG emissions than gasoline. Assuming the availability of a fuel cell vehicle with about twice the efficiency of a vehicle with a combustion engine, GHG emissions would be 51% lower. Based on LEM, GHG emissions from hydrogen are 21 - 54% lower, depending on whether combustion engines or fuel cells are assumed. Assuming hydrolysis, GHGenius estimates the GHG emissions for hydrogen to range from an increase of 9% with combustion engine vehicles to a decrease of 46% with fuel cell vehicles. With less hydro and nuclear power in the mix, LEM results range from an increase of 130% with combustion engine vehicles to an increase of 21% with fuel cell vehicles.

Regardless of the model used, much lower CO_2 emissions can be achieved by using electricity produced from CO_2-free sources to displace coal-fired powerplants. By replacing gasoline with hydrogen produced from non-fossil resources, CO_2 emissions are reduced by 0.18 kilograms for each kilowatt-hour (kWh) of electricity used to replace gasoline with hydrogen produced by the electrolysis of water.[36] At an estimated 0.96 kg/kWh for the carbon dioxide emissions rate from coal-fired electricity generation,[37] using the same amount of non-fossil electricity to replace electricity generated by coal would have saved 0.96 kg of CO_2. Even 1 kWh of electricity produced from natural gas produces 0.60 kg of CO_2. Therefore, CO_2 emissions could be much more efficiently reduced by using any available non-fossil electricity to displace electricity that is currently being produced by fossil fuel. Until all electricity produced by fossil fuels has been eliminated, using any available non-fossil electricity to produce hydrogen for use in transportation leads to increased CO_2 emissions.

Biodiesel – A mixture of fatty acid methyl esters (FAME) produced from vegetable oil, pure biodiesel has about 7 to11 percent lower energy content per gallon than Diesel fuel.[38, 39, 40] Given these characteristics, Diesel engines will run on pure biodiesel, although they will produce about 7 to 11 percent less power. However, depending on the particular engine, biodiesel may cause deterioration of the seals and hoses used in the fuel systems. (Late-model Diesel engines are compatible with 5 percent biodiesel blended into conventional Diesel fuel.) In addition, wax crystals form in biodiesel at temperatures slightly above 0°C, so it cannot be used at as low a temperature as conventional Diesel fuel without the use of additives to prevent the formation of wax crystals.

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[36] Assuming 70% efficiency for the production and compression of hydrogen using electrolysis, each kWh of electricity produces 2,388 BTU of hydrogen, which is approximately 7.86% of the energy in a litre of gasoline. Each litre of gasoline produces 2.343 kg of CO_2 when burned, so the hydrogen produced using 1 kWh of electricity eliminates 0.18 kg of CO_2 (0.0786 * 2.343).

[37] W. Barbour, et al, "Carbon Dioxide Emissions from the Generation of Electric Power in the United States," U.S. Department of Energy and U.S. Environmental Protection Agency, July 2000.

[38] "Biodiesel – Clean, Green Diesel Fuel," National Renewable Energy Laboratory, U.S. Department of Energy, February 2002.

[39] http://www.eere.energy.gov/afdc/pdfs/fueltable.pdf

[40] "Annual Energy Outlook 2007," U.S. Energy Information Administration, Report No. DOE/EIA-0383, February 2007.

To minimize the problems associated with operation on pure biodiesel, it is commonly blended with conventional Diesel fuel. A blend containing 5 percent biodiesel is referred to as "B5." A blend with 20 percent biodiesel is referred to as "B20." Because of the lower energy content, a B20 blend reduces fuel economy by about two percent.

Energy Efficiency – A joint DOE/USDA study published in 1998 is the source of the often-stated conclusion that biodiesel provides 3.2 units of energy per unit of fossil fuel input.[41] In contrast, Pimentel and Patzek concluded that there is a net energy loss associated with biodiesel production.[42] Van Gerpen and Shrestha explain the differences in assumptions between the two analyses, identify errors in the Pimentel and Patzek work, and conclude that the net energy gain calculated by DOE/USDA is reasonable.[43]

Cost – Because biodiesel can be made from a variety of feedstocks, the production cost depends on the cost of the feedstock. The least expensive feedstock is waste cooking oil/fat. However, the cost of biodiesel made from waste oils and fats is not particularly relevant because the volume of such feedstock is limited. To produce biodiesel in significant quantities, it needs to be produced from an agricultural product like soybean oil.

A 2004 estimate by the Energy Information Administration[44] projected the production cost of biodiesel to be approximately three times the cost of conventional Diesel fuel. The increase in oil prices since 2004 has increased the cost of conventional Diesel fuel; however, soybean prices have also been increasing due to the increased demand for biodiesel created by mandates and subsidies. The current market is volatile, but biodiesel prices are expected to remain significantly higher than the price of conventional Diesel fuel.

Emissions – Based on analysis by EPA, DOE reports[45] that pure biodiesel used in pre-1998 engines reduces HC emissions by over 60 percent, reduces PM and CO emissions by almost 50 percent, and increases NOx emissions by 10 percent. Since HC and CO emissions are inherently low in Diesel engines, the significant effects are the 50 percent reduction in PM offset by the 10 percent increase in NOx. In newer engines, the NOx emissions increase by about 30 percent, but PM emissions decrease by about 75 percent. Historically, this would have been considered a good trade-off, but PM and NOx emissions standards required in the immediate future will reduce the significance of the emissions effect.

Based on GHGenius, pure biodiesel reduces GHG emissions by 73%. Based on LEM, GHG emissions from biodiesel are 15% higher. The LEM estimates are significantly

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[41] "Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus," Report No. NREL/SR-580-24089, U.S. Department of Agriculture and U.S. Department of Energy, May 1998.

[42] D. Pimentel and T. W. Patzek, "Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower," Natural Resources Research, Vol. 14, No. 1, March 2005.

[43] J. Van Gerpen and D. Shrestha, "Biodiesel Energy Balance," Department of Biological and Agricultural Engineering, University of Idaho, 2005 or 2006.

[44] A. Radich, "Biodiesel Performance, Costs, and Use," U.S. Department of Energy, Energy Information Administration, 2004.

[45] Bob McCormick, "Effects of Biodiesel on Pollutant Emissions," National Renewable Energy Laboratory, U.S. Department of Energy, March 16, 2005.

higher for the "fuel production," "fertilizer and feedstock production," and "land use and cultivation" stages. The main reason for the difference is that LEM estimates much larger emissions from land use changes and cultivation. LEM assumes additional land is brought into production to produce soybeans; GHGenius assumes soybean production replaces an existing agricultural operation. Since the demand for other agricultural products is not reduced by biodiesel production, the assumptions built into LEM appear to be more reasonable.

"Clean Diesel" – Diesel-powered vehicles meeting Tier 2 emissions standards are sometimes called "Clean Diesels." Because it has been used by heavy-duty trucks for many years, Diesel fuel may not be considered an alternative fuel but "Clean Diesels" require a special type of Diesel fuel with ultra low sulfur content. Like conventional Diesel fuel, Clean Diesel is a "distillate" refined from crude oil but it must undergo intensive desulfurization after the initial distillation process. Under EPA regulations, ultra low sulfur Clean Diesel has been phasing into the system. By June 2006, 80 percent of the highway Diesel fuel sold in the U.S. had to meet a 15 ppm sulfur standard, which is a 97 percent reduction from the previous sulfur standard. By December 1, 2010, all on-highway Diesel fuel must meet the 15 ppm standard. By the end of 2014, nearly all off-highway Diesel fuel will meet the same standard.

Energy Efficiency – There are two factors affecting the energy efficiency associated with the use of Clean Diesel. First, the refining process for Diesel fuel is more energy efficient than the refining process for gasoline. Gasoline is produced with an energy efficiency of approximately 86 percent, i.e., about 14 percent of the energy in the crude oil is lost in the production of the gasoline.[46] In contrast, it is estimated that Diesel fuel is produced with an energy efficiency of about 91 percent; only 9 percent of the energy in the crude oil is lost. The second factor affecting the energy efficiency of Clean Diesel is the inherently lower fuel consumption of Diesel engines compared to gasoline engines, particularly at light loads. Based on vehicle simulation modeling by Sierra Research, the fuel consumption reduction achievable with a Diesel engine in a typical midsize car is approximately 21 percent. This corresponds to a 27 percent improvement in fuel economy expressed in miles per gallon.

Cost – Due to its lower refining cost, Diesel fuel has historically been less expensive than gasoline. However, a combination of increased global demand for Diesel fuel, higher taxes on Diesel fuel, and the costs of meeting the ultra low sulfur standard has recently caused the price of Diesel fuel to exceed the price of gasoline. At the beginning of 2009, the Energy Information Administration reported that U.S. average retail prices for Diesel fuel were US$0.61 per gallon (36.0 percent) higher than for gasoline. Since then, however, Diesel costs have come down relative to gasoline.

Another cost factor associated with using Clean Diesel rather than gasoline is higher vehicle cost. Based on a 2008 study by Sierra Research, the increase in retail price

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[46] Wang, M. et al., "Allocation of Energy Use in Petroleum Refineries to Petroleum Products Implications for Life-Cycle Energy Use and Emission Inventory of Petroleum Transportation Fuels," Center for Transportation Research, Energy Systems Division, Argonne National Laboratory, 2003.

associated with replacing a gasoline engine with a Diesel engine in a midsize car is approximately US$6,000.[47]

Emissions – Due to its low sulfur content, Clean Diesel fuel enables the use of catalytic converters and catalyzed particulate traps, which allow Diesel-powered vehicles to meet the same Tier 2 emissions standards that apply to gasoline-fueled vehicles. Diesel-powered vehicles also produce lower GHG emissions than conventional gasoline-powered vehicles due to their higher fuel economy. However, the higher carbon content of Diesel fuel results in a lower reduction in CO_2 emissions than in fuel consumption. When the higher fuel carbon content is accounted for, a Diesel vehicle that has the same fuel economy as a gasoline vehicle emits about 15 percent higher CO_2 emissions. As a result, the 21 percent reduction in fuel consumption associated with replacing a gasoline engine with a Diesel engine results in a 9 percent reduction in CO_2 emissions.

Fischer-Tropsch Gasoline and Diesel – The Fischer-Tropsch (FT) process involves the production of liquid hydrocarbons from a reaction between carbon monoxide and hydrogen in the presence of an iron or cobalt catalyst. It was developed during the 1920s in Germany by Franz Fischer and Hans Tropsch. The hydrogen and carbon monoxide, which are referred to as "synthesis gas," can be produced from the partial combustion variety of feedstocks, including natural gas, biomass, and coal. The FT process can therefore be used to expand the range of fossil resources from which gasoline and Diesel fuel are produced.

Energy Efficiency – Because both steps in the process—the creation of synthesis gas and the synthesis gas to liquid hydrocarbon reaction—involve partial combustion, the energy used to create the end product is significantly greater than the energy required to refine crude oil into conventional gasoline or Diesel fuel. A 2001 study for the U.S. Department of Energy estimates the energy efficiency of Fischer-Tropsch gasoline and Diesel production from coal at 52.0 percent and 50.4 percent respectively. [48]

Cost – The greater energy required to produce FT liquids is offset by the lower cost and greater availability of the feedstocks. The above-referenced 2001 study for the U.S. Department of Energy projects that FT liquids could be produced from coal for US$1.04 to $1.24 gallon, which would make them competitive at current oil prices. There are only a few commercial FT fuel production facilities in operation (e.g., one in Malaysia and one in South Africa) because production costs have historically been higher than for the production of gasoline and Diesel fuel from crude oil. Whether significantly greater use of the FT process occurs in the future will likely depend on whether crude oil prices stay above US$50 per bbl for an extended period of time and whether the mitigation of higher GHG emissions is required.

Emissions – Since synthetic gasoline or Diesel fuel produced using the FT process has characteristics similar to those of conventional fuels, no significant difference in vehicle emissions is expected. However, depending on the feedstock, GHG emissions can be

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[47] T.C. Austin, et al., "Basic Analysis of the Cost and Long-Term Impact of the Energy Independence and Security Act Fuel Economy Standards," Sierra Research Report No. SR2008-04-01, April 24, 2008.

[48] J. J. Marano and J. P. Ciferno, "Life-Cycle Greenhouse-Gas Emissions Inventory For Fischer-Tropsch Fuels," Energy and Environmental Solutions, LLC, June 2001.

higher or lower. With fossil fuel feedstocks like coal, GHG emissions will be higher unless the CO_2 emissions generated are sequestered. Other techniques for reducing GHG emissions when using FT to produce fuel from coal include coal bed methane capture, coprocessing of coal and biomass, and coproduction of fuel and electric power. Further research is needed to determine the cost implications of these techniques; however, the potential exists for FT Diesel and gasoline to have lower GHG emissions than are associated with conventional fuels.

Summary – Table B-2 compares the potential advantages of the alternatives discussed above to their disadvantages. With the exception of gasoline and Diesel produced from fossil fuels using the Fischer-Tropsch process, all of the alternatives have the disadvantage of either higher vehicle cost or higher fuel cost. This fundamental problem explains why alternatives, thus far, have not succeeded in the marketplace without government subsidies.

Table B-2
Potential Advantages and Disadvantages
Of Alternative Transportation Fuels

Fuel	Potential Advantages	Disadvantages
Electricity	Zero vehicle emissions Lower GHG emissions	Much higher vehicle cost Higher NOx emissions[a] Limited refueling infrastructure
Ethanol	Lower GHG emissions Available from biomass	Higher cost Poor net energy balance Higher CAC emissions Lack of refueling infrastructure
Natural Gas	Lower GHG emissions	Higher vehicle cost Limited refueling infrastructure
LPG	Lower GHG emissions	Inadequate supply
Methanol	Renewable/alternative sources Lower GHG emissions	Higher cost if from renewables Higher GHG emissions if from fossil fuels Lack of refueling infrastructure
Hydrogen	Low or zero vehicle emissions Renewable/alternative sources	Much higher fuel cost Lack of refueling infrastructure
Biodiesel	Lower GHG emissions Available from biomass	Probably higher GHG emissions[b] Higher cost Higher NOx emissions
Clean Diesel	Lower GHG emissions	Higher vehicle cost relative to gasoline
Fischer-Tropsch Gas/Diesel	Renewable/alternative sources	Higher GHG emissions[c]

[a] Unless from clean, renewable source or Selective Catalytic Reduction (SCR) NOx control

[b] Unless no net increase in farm land

[c] Unless CO_2 sequestration used

Appendix C
MOBILE Modeling Results

Lower Fraser Valley, Emission Inventory (Tonnes per Year), Calendar Year = 2005

Class 2b Included in Light-Duty Totals, Total GHGs = CO2+N2O+CH4

I/M Case	% GLL Inclusion	Species	Vehicle Class					
			LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
None	100%	Exhaust VOC	11,384	39	194	32	142	11,790
		Evaporative VOC	7,565	35	83	0	0	7,683
		Total VOC	18,949	74	276	32	142	19,473
		Exhaust CO	262,597	949	1,248	91	811	265,697
		Exhaust NOx	16,376	153	107	229	3,545	20,411
		Exhaust PM2.5	75	2	1	11	84	173
		Tire/Brake PM2.5	60	0	0	0	1	62
		Exhaust SO2	78	0	0	6	52	137
		Exhaust CO2	5,037,129	27,007	12,416	54,482	444,117	5,575,149
		Exhaust N20	339	2	0	0	4	345
		Exhaust CH4	689	4	14	1	10	717
		Total GHGs (CO2eq)	5,250,891	28,134	16,461	54,795	447,206	5,797,487
Current	100%	Exhaust VOC	8,842	39	194	32	139	9,246
		Evaporative VOC	7,433	35	83	0	0	7,551
		Total VOC	16,275	74	276	32	139	16,797
		Exhaust CO	212,456	949	1,248	91	811	215,556
		Exhaust NOx	14,144	153	107	228	3,528	18,161
		Exhaust PM2.5	75	2	1	11	82	171
		Tire/Brake PM2.5	60	0	0	0	1	62
		Exhaust SO2	78	0	0	6	52	137
		Exhaust CO2	4,963,289	27,007	12,416	54,482	444,117	5,501,309
		Exhaust N20	333	2	0	0	4	339
		Exhaust CH4	689	4	14	1	10	717
		Total GHGs (CO2eq)	5,176,902	28,134	16,461	54,795	447,206	5,723,497

Lower Fraser Valley, I/M Program Benefit (Tonnes per Year), Calendar Year = 2005
Relative to MOBILE No I/M Case, Calendar Year = 2005
Class 2b Included in Light-Duty Totals, Total GHGs = CO2+N2O+CH4

I/M Case	% GLL Inclusion	Species	Vehicle Class LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
Current	100%	Exhaust VOC	2,542	0	0	0	2	2,544
		Evaporative VOC	132	0	0	0	0	132
		Total VOC	2,674	0	0	0	2	2,676
		Exhaust CO	50,140	0	0	0	0	50,140
		Exhaust NOx	2,231	0	0	1	18	2,250
		Exhaust PM2.5	0	0	0	0	2	2
		Tire/Brake PM2.5	0	0	0	0	0	0
		Exhaust SO2	0	0	0	0	0	0
		Exhaust CO2	73,840	0	0	0	0	73,840
		Exhaust N20	6	0	0	0	0	6
		Exhaust CH4	0	0	0	0	0	0
		Total GHGs (CO2eq)	73,989	0	0	0	0	73,989

Lower Fraser Valley, I/M Program Benefit (%), Calendar Year = 2005
Relative to MOBILE No I/M Case, Calendar Year = 2005
Class 2b Included in Light-Duty Totals, Total GHGs = CO2+N2O+CH4

I/M Case	% GLL Inclusion	Species	Vehicle Class LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
Current	0%	Exhaust VOC	22.3%	0.0%	0.0%	0.5%	1.7%	21.6%
		Evaporative VOC	1.7%	0.0%	0.0%	0.0%	0.0%	1.7%
		Total VOC	14.1%	0.0%	0.0%	0.5%	1.7%	13.7%
		Exhaust CO	19.1%	0.0%	0.0%	0.0%	0.0%	18.9%
		Exhaust NOx	13.6%	0.0%	0.0%	0.4%	0.5%	11.0%
		Exhaust PM2.5	0.0%	0.0%	0.0%	1.1%	2.3%	1.2%
		Tire/Brake PM2.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust SO2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust CO2	1.5%	0.0%	0.0%	0.0%	0.0%	1.3%
		Exhaust N20	1.8%	0.0%	0.0%	0.0%	0.0%	1.7%
		Exhaust CH4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Total GHGs (CO2eq)	1.4%	0.0%	0.0%	0.0%	0.0%	1.3%

Lower Fraser Valley, Emission Inventory (Tonnes per Year), Calendar Year = 2010

Class 2b Included in Light-Duty Totals, Total GHGs = CO2+N2O+CH4

I/M Case	% GLL Inclusion	Species	Vehicle Class					
			LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
None, MOBILE No I/M Baseline	100%	Exhaust VOC	6,567	16	168	29	107	6,887
		Evaporative VOC	6,177	29	59	0	0	6,265
		Total VOC	12,744	45	227	29	107	13,153
		Exhaust CO	189,220	362	1,161	70	523	191,336
		Exhaust NOx	11,966	102	93	177	2,323	14,662
		Exhaust PM2.5	61.8	1.2	1.1	7.1	41.1	112.1
		Tire/Brake PM2.5	63.8	0.1	0.4	0.4	1.6	66.4
		Exhaust SO2	102.5	0.5	0.2	0.5	4.5	108.2
		Exhaust NH3	1,208.3	1.1	0.8	1.6	8.2	1,220.1
		Exhaust CO2	5,237,455	27,404	12,654	57,445	480,593	5,815,551
		Exhaust N20	227	1	0	1	4	234
		Exhaust CH4	499	2	14	1	8	523
		Total GHGs (CO2eq)	5,391,760	28,044	16,738	57,658	483,019	5,977,219
None, Modified No I/M Baseline	100%	Exhaust VOC	7,476	16	168	29	107	7,796
		Evaporative VOC	6,177	29	59	0	0	6,265
		Total VOC	13,653	45	227	29	107	14,062
		Exhaust CO	206,947	362	1,161	70	523	209,063
		Exhaust NOx	13,010	102	93	177	2,323	15,706
		Exhaust PM2.5	61.8	1.2	1.1	7.1	41.1	112.1
		Tire/Brake PM2.5	63.8	0.1	0.4	0.4	1.6	66.4
		Exhaust SO2	102.5	0.5	0.2	0.5	4.5	108.2
		Exhaust NH3	1,208.3	1.1	0.8	1.6	8.2	1,220.1
		Exhaust CO2	5,237,455	27,404	12,654	57,445	480,593	5,815,551
		Exhaust N20	227	1	0	1	4	234
		Exhaust CH4	499	2	14	1	8	523
		Total GHGs (CO2eq)	5,391,760	28,044	16,738	57,658	483,019	5,977,219
Current	100%	Exhaust VOC	5,043	16	168	29	105	5,361
		Evaporative VOC	6,049	29	59	0	0	6,137
		Total VOC	11,092	45	227	29	105	11,498
		Exhaust CO	159,237	362	1,161	70	523	161,353
		Exhaust NOx	10,268	102	93	176	2,312	12,950
		Exhaust PM2.5	61.8	1.2	1.1	7.0	40.0	111.0
		Tire/Brake PM2.5	63.8	0.1	0.4	0.4	1.6	66.4
		Exhaust SO2	102.5	0.5	0.2	0.5	4.5	108.2
		Exhaust NH3	1,208.3	1.1	0.8	1.6	8.2	1,220.1
		Exhaust CO2	5,172,150	27,404	12,654	57,445	480,593	5,750,246
		Exhaust N20	227	1	0	1	4	233
		Exhaust CH4	499	2	14	1	8	523
		Total GHGs (CO2eq)	5,326,451	28,044	16,738	57,658	483,019	5,911,909

Lower Fraser Valley, Emission Inventory (Tonnes per Year), Calendar Year = 2010

Class 2b Included in Light-Duty Totals, Total GHGs = CO2+N2O+CH4

I/M Case	% GLL Inclusion	Species	Vehicle Class					
			LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
Alternative	50%	Exhaust VOC	4,965	16	168	29	105	5,283
		Evaporative VOC	3,762	29	59	0	0	3,850
		Total VOC	8,727	45	227	29	105	9,133
		Exhaust CO	157,904	362	1,161	70	523	160,019
		Exhaust NOx	10,176	102	93	176	2,312	12,859
		Exhaust PM2.5	61.8	1.2	1.1	7.0	40.0	111.0
		Tire/Brake PM2.5	63.8	0.1	0.4	0.4	1.6	66.4
		Exhaust SO2	102.5	0.5	0.2	0.5	4.5	108.2
		Exhaust NH3	1,208.3	1.1	0.8	1.6	8.2	1,220.1
		Exhaust CO2	5,165,827	27,404	12,654	57,445	480,593	5,743,923
		Exhaust N20	226	1	0	1	4	232
		Exhaust CH4	499	2	14	1	8	523
		Total GHGs (CO2eq)	5,320,103	28,044	16,738	57,658	483,019	5,905,561

Lower Fraser Valley, I/M Program Benefit (Tonnes per Year)
Relative to MOBILE No I/M Case, Calendar Year = 2010
Class 2b Included in Light-Duty Totals, Total GHGs = CO2+N2O+CH4

I/M Case	% GLL Inclusion	Species	Vehicle Class					
			LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
Current	100%	Exhaust VOC	1,524	0	0	0	2	1,527
		Evaporative VOC	128	0	0	0	0	128
		Total VOC	1,653	0	0	0	2	1,655
		Exhaust CO	29,982	0	0	0	0	29,982
		Exhaust NOx	1,699	0	0	1	12	1,711
		Exhaust PM2.5	0.0	0.0	0.0	0.1	1.0	1.1
		Tire/Brake PM2.5	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust SO2	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust NH3	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust CO2	65,305	0	0	0	0	65,305
		Exhaust N20	0	0	0	0	0	0
		Exhaust CH4	0	0	0	0	0	0
		Total GHGs (CO2eq)	65,309	0	0	0	0	65,309
Alternative	50%	Exhaust VOC	1,602	0	0	0	2	1,604
		Evaporative VOC	2,415	0	0	0	0	2,415
		Total VOC	4,018	0	0	0	2	4,020
		Exhaust CO	31,316	0	0	0	0	31,316
		Exhaust NOx	1,791	0	0	1	12	1,803
		Exhaust PM2.5	0.0	0.0	0.0	0.1	1.0	1.1
		Tire/Brake PM2.5	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust SO2	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust NH3	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust CO2	71,628	0	0	0	0	71,628
		Exhaust N20	1	0	0	0	0	1
		Exhaust CH4	0	0	0	0	0	0
		Total GHGs (CO2eq)	71,657	0	0	0	0	71,657

Lower Fraser Valley, I/M Program Benefit (Tonnes per Year)
Relative to Modified No I/M Case, Calendar Year = 2010
Class 2b Included in Light-Duty Totals, Total GHGs = CO2+N2O+CH4

I/M Case	% GLL Inclusion	Species	Vehicle Class LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
Current	100%	Exhaust VOC	2,433	0	0	0	2	2,436
		Evaporative VOC	128	0	0	0	0	128
		Total VOC	2,562	0	0	0	2	2,564
		Exhaust CO	47,710	0	0	0	0	47,710
		Exhaust NOx	2,743	0	0	1	12	2,755
		Exhaust PM2.5	0.0	0.0	0.0	0.1	1.0	1.1
		Tire/Brake PM2.5	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust SO2	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust NH3	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust CO2	65,305	0	0	0	0	65,305
		Exhaust N20	0	0	0	0	0	0
		Exhaust CH4	0	0	0	0	0	0
		Total GHGs (CO2eq)	65,309	0	0	0	0	65,309
Alternative	50%	Exhaust VOC	2,511	0	0	0	2	2,513
		Evaporative VOC	2,415	0	0	0	0	2,415
		Total VOC	4,927	0	0	0	2	4,929
		Exhaust CO	49,043	0	0	0	0	49,043
		Exhaust NOx	2,835	0	0	1	12	2,847
		Exhaust PM2.5	0.0	0.0	0.0	0.1	1.0	1.1
		Tire/Brake PM2.5	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust SO2	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust NH3	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust CO2	71,628	0	0	0	0	71,628
		Exhaust N20	1	0	0	0	0	1
		Exhaust CH4	0	0	0	0	0	0
		Total GHGs (CO2eq)	71,657	0	0	0	0	71,657

Lower Fraser Valley, I/M Program Benefit (%)
Relative to MOBILE No I/M Case, Calendar Year = 2010
Class 2b Included in Light-Duty Totals, Total GHGs = CO2+N2O+CH4

I/M Case	% GLL Inclusion	Species	Vehicle Class					
			LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
Current	100%	Exhaust VOC	23.2%	0.0%	0.0%	0.5%	1.8%	22.2%
		Evaporative VOC	2.1%	0.0%	0.0%	0.0%	0.0%	2.0%
		Total VOC	13.0%	0.0%	0.0%	0.5%	1.8%	12.6%
		Exhaust CO	15.8%	0.0%	0.0%	0.0%	0.0%	15.7%
		Exhaust NOx	14.2%	0.0%	0.0%	0.4%	0.5%	11.7%
		Exhaust PM2.5	0.0%	0.0%	0.0%	1.3%	2.5%	1.0%
		Tire/Brake PM2.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust SO2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust NH3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust CO2	1.2%	0.0%	0.0%	0.0%	0.0%	1.1%
		Exhaust N20	0.1%	0.0%	0.0%	0.0%	0.0%	0.1%
		Exhaust CH4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Total GHGs (CO2eq)	1.2%	0.0%	0.0%	0.0%	0.0%	1.1%
Alternative	50%	Exhaust VOC	24.4%	0.0%	0.0%	0.5%	1.8%	23.3%
		Evaporative VOC	39.1%	0.0%	0.0%	0.0%	0.0%	38.6%
		Total VOC	31.5%	0.0%	0.0%	0.5%	1.8%	30.6%
		Exhaust CO	16.6%	0.0%	0.0%	0.0%	0.0%	16.4%
		Exhaust NOx	15.0%	0.0%	0.0%	0.4%	0.5%	12.3%
		Exhaust PM2.5	0.0%	0.0%	0.0%	1.3%	2.5%	1.0%
		Tire/Brake PM2.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust SO2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust NH3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust CO2	1.4%	0.0%	0.0%	0.0%	0.0%	1.2%
		Exhaust N20	0.5%	0.0%	0.0%	0.0%	0.0%	0.5%
		Exhaust CH4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Total GHGs (CO2eq)	1.3%	0.0%	0.0%	0.0%	0.0%	1.2%

Lower Fraser Valley, I/M Program Benefit (%)
Relative to Modified No I/M Case, Calendar Year = 2010
Class 2b Included in Light-Duty Totals, Total GHGs = CO2+N2O+CH4

I/M Case	% GLL Inclusion	Species	Vehicle Class					
			LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
Current	100%	Exhaust VOC	32.5%	0.0%	0.0%	0.5%	1.8%	31.2%
		Evaporative VOC	2.1%	0.0%	0.0%	0.0%	0.0%	2.0%
		Total VOC	18.8%	0.0%	0.0%	0.5%	1.8%	18.2%
		Exhaust CO	23.1%	0.0%	0.0%	0.0%	0.0%	22.8%
		Exhaust NOx	21.1%	0.0%	0.0%	0.4%	0.5%	17.5%
		Exhaust PM2.5	0.0%	0.0%	0.0%	1.3%	2.5%	1.0%
		Tire/Brake PM2.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust SO2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust NH3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust CO2	1.2%	0.0%	0.0%	0.0%	0.0%	1.1%
		Exhaust N20	0.1%	0.0%	0.0%	0.0%	0.0%	0.1%
		Exhaust CH4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Total GHGs (CO2eq)	1.2%	0.0%	0.0%	0.0%	0.0%	1.1%
Alternative	50%	Exhaust VOC	33.6%	0.0%	0.0%	0.5%	1.8%	32.2%
		Evaporative VOC	39.1%	0.0%	0.0%	0.0%	0.0%	38.6%
		Total VOC	36.1%	0.0%	0.0%	0.5%	1.8%	35.1%
		Exhaust CO	23.7%	0.0%	0.0%	0.0%	0.0%	23.5%
		Exhaust NOx	21.8%	0.0%	0.0%	0.4%	0.5%	18.1%
		Exhaust PM2.5	0.0%	0.0%	0.0%	1.3%	2.5%	1.0%
		Tire/Brake PM2.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust SO2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust NH3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust CO2	1.4%	0.0%	0.0%	0.0%	0.0%	1.2%
		Exhaust N20	0.5%	0.0%	0.0%	0.0%	0.0%	0.5%
		Exhaust CH4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Total GHGs (CO2eq)	1.3%	0.0%	0.0%	0.0%	0.0%	1.2%

Lower Fraser Valley, Emission Inventory (Tonnes per Year), Calendar Year = 2015

Class 2b Included in Light-Duty Totals, Total GHGs = CO2+N2O+CH4

I/M Case	% GLL Inclusion	Species	Vehicle Class					
			LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
None, MOBILE No I/M Baseline	100%	Exhaust VOC	4,671	9	139	26	94	4,938
		Evaporative VOC	4,016	31	44	0	0	4,090
		Total VOC	8,686	40	183	26	94	9,028
		Exhaust CO	161,372	286	1,233	56	289	163,237
		Exhaust NOx	8,568	65	75	120	1,333	10,162
		Exhaust PM2.5	55.4	0.7	1.1	4.3	22.8	84.3
		Tire/Brake PM2.5	67.9	0.1	0.4	0.5	1.8	70.7
		Exhaust SO2	111.0	0.5	0.3	0.6	4.9	117.2
		Exhaust NH3	1,292.6	1.2	0.9	1.8	9.0	1,305.4
		Exhaust CO2	5,226,654	27,845	13,367	63,051	523,667	5,854,585
		Exhaust N20	171	1	0	1	4	177
		Exhaust CH4	385	1	14	0	7	407
		Total GHGs (CO2eq)	5,345,572	28,145	17,637	63,209	525,730	5,980,292
None, Modified No I/M Baseline	100%	Exhaust VOC	5,947	9	139	26	94	6,214
		Evaporative VOC	4,016	31	44	0	0	4,090
		Total VOC	9,962	40	183	26	94	10,304
		Exhaust CO	185,539	286	1,233	56	289	187,403
		Exhaust NOx	10,122	65	75	120	1,333	11,716
		Exhaust PM2.5	55.4	0.7	1.1	4.3	22.8	84.3
		Tire/Brake PM2.5	67.9	0.1	0.4	0.5	1.8	70.7
		Exhaust SO2	111.0	0.5	0.3	0.6	4.9	117.2
		Exhaust NH3	1,292.6	1.2	0.9	1.8	9.0	1,305.4
		Exhaust CO2	5,226,654	27,845	13,367	63,051	523,667	5,854,585
		Exhaust N20	171	1	0	1	4	177
		Exhaust CH4	385	1	14	0	7	407
		Total GHGs (CO2eq)	5,345,572	28,145	17,637	63,209	525,730	5,980,292
Current	100%	Exhaust VOC	3,237	9	139	25	92	3,502
		Evaporative VOC	3,866	31	44	0	0	3,941
		Total VOC	7,103	40	183	25	92	7,443
		Exhaust CO	133,688	286	1,233	56	289	135,552
		Exhaust NOx	6,867	65	75	120	1,326	8,454
		Exhaust PM2.5	55.4	0.7	1.1	4.2	22.2	83.7
		Tire/Brake PM2.5	67.9	0.1	0.4	0.5	1.8	70.7
		Exhaust SO2	111.0	0.5	0.3	0.6	4.9	117.2
		Exhaust NH3	1,292.6	1.2	0.9	1.8	9.0	1,305.4
		Exhaust CO2	5,167,566	27,845	13,367	63,051	523,667	5,795,496
		Exhaust N20	169	1	0	1	4	175
		Exhaust CH4	385	1	14	0	7	407
		Total GHGs (CO2eq)	5,286,426	28,145	17,637	63,209	525,730	5,921,146

Lower Fraser Valley, Emission Inventory (Tonnes per Year), Calendar Year = 2015

Class 2b Included in Light-Duty Totals, Total GHGs = CO2+N2O+CH4

I/M Case	% GLL Inclusion	Species	Vehicle Class LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
Alternative	50%	Exhaust VOC	3,164	9	139	25	92	3,429
		Evaporative VOC	2,375	31	44	0	0	2,450
		Total VOC	5,539	40	183	25	92	5,879
		Exhaust CO	132,409	286	1,233	56	289	134,274
		Exhaust NOx	6,762	65	75	120	1,326	8,349
		Exhaust PM2.5	55.4	0.7	1.1	4.2	22.2	83.7
		Tire/Brake PM2.5	67.9	0.1	0.4	0.5	1.8	70.7
		Exhaust SO2	111.0	0.5	0.3	0.6	4.9	117.2
		Exhaust NH3	1,292.6	1.2	0.9	1.8	9.0	1,305.4
		Exhaust CO2	5,163,168	27,845	13,367	63,051	523,667	5,791,099
		Exhaust N20	169	1	0	1	4	175
		Exhaust CH4	385	1	14	0	7	407
		Total GHGs (CO2eq)	5,282,029	28,145	17,637	63,209	525,730	5,916,749

Lower Fraser Valley, I/M Program Benefit (Tonnes per Year)
Relative to MOBILE No I/M Case, Calendar Year = 2015
Class 2b Included in Light-Duty Totals, Total GHGs = CO2+N2O+CH4

I/M Case	% GLL Inclusion	Species	Vehicle Class LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
Current	100%	Exhaust VOC	1,434	0	0	0	2	1,436
		Evaporative VOC	150	0	0	0	0	150
		Total VOC	1,583	0	0	0	2	1,585
		Exhaust CO	27,684	0	0	0	0	27,684
		Exhaust NOx	1,701	0	0	0	7	1,708
		Exhaust PM2.5	0.0	0.0	0.0	0.0	0.5	0.6
		Tire/Brake PM2.5	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust SO2	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust NH3	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust CO2	59,089	0	0	0	0	59,089
		Exhaust N20	2	0	0	0	0	2
		Exhaust CH4	0	0	0	0	0	0
		Total GHGs (CO2eq)	59,146	0	0	0	0	59,146
Alternative	50%	Exhaust VOC	1,507	0	0	0	2	1,509
		Evaporative VOC	1,640	0	0	0	0	1,640
		Total VOC	3,148	0	0	0	2	3,149
		Exhaust CO	28,963	0	0	0	0	28,963
		Exhaust NOx	1,806	0	0	0	7	1,813
		Exhaust PM2.5	0.0	0.0	0.0	0.0	0.5	0.6
		Tire/Brake PM2.5	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust SO2	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust NH3	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust CO2	63,486	0	0	0	0	63,486
		Exhaust N20	2	0	0	0	0	2
		Exhaust CH4	0	0	0	0	0	0
		Total GHGs (CO2eq)	63,544	0	0	0	0	63,544

Lower Fraser Valley, I/M Program Benefit (Tonnes per Year)
Relative to Modified No I/M Case, Calendar Year = 2015
Class 2b Included in Light-Duty Totals, Total GHGs = CO2+N2O+CH4

I/M Case	% GLL Inclusion	Species	Vehicle Class					
			LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
Current	100%	Exhaust VOC	2,710	0	0	0	2	2,712
		Evaporative VOC	150	0	0	0	0	150
		Total VOC	2,859	0	0	0	2	2,861
		Exhaust CO	51,851	0	0	0	0	51,851
		Exhaust NOx	3,256	0	0	0	7	3,263
		Exhaust PM2.5	0.0	0.0	0.0	0.0	0.5	0.6
		Tire/Brake PM2.5	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust SO2	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust NH3	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust CO2	59,089	0	0	0	0	59,089
		Exhaust N20	2	0	0	0	0	2
		Exhaust CH4	0	0	0	0	0	0
		Total GHGs (CO2eq)	59,146	0	0	0	0	59,146
Alternative	50%	Exhaust VOC	2,783	0	0	0	2	2,785
		Evaporative VOC	1,640	0	0	0	0	1,640
		Total VOC	4,424	0	0	0	2	4,425
		Exhaust CO	53,129	0	0	0	0	53,129
		Exhaust NOx	3,360	0	0	0	7	3,367
		Exhaust PM2.5	0.0	0.0	0.0	0.0	0.5	0.6
		Tire/Brake PM2.5	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust SO2	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust NH3	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust CO2	63,486	0	0	0	0	63,486
		Exhaust N20	2	0	0	0	0	2
		Exhaust CH4	0	0	0	0	0	0
		Total GHGs (CO2eq)	63,544	0	0	0	0	63,544

Lower Fraser Valley, I/M Program Benefit (%)
Relative to MOBILE No I/M Case, Calendar Year = 2015
Class 2b Included in Light-Duty Totals, Total GHGs = CO2+N2O+CH4

I/M Case	% GLL Inclusion	Species	Vehicle Class					
			LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
Current	100%	Exhaust VOC	30.7%	0.0%	0.0%	0.5%	1.8%	29.1%
		Evaporative VOC	3.7%	0.0%	0.0%	0.0%	0.0%	3.7%
		Total VOC	18.2%	0.0%	0.0%	0.5%	1.8%	17.6%
		Exhaust CO	17.2%	0.0%	0.0%	0.0%	0.0%	17.0%
		Exhaust NOx	19.9%	0.0%	0.0%	0.4%	0.5%	16.8%
		Exhaust PM2.5	0.0%	0.0%	0.0%	1.2%	2.4%	0.7%
		Tire/Brake PM2.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust SO2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust NH3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust CO2	1.1%	0.0%	0.0%	0.0%	0.0%	1.0%
		Exhaust N20	1.3%	0.0%	0.0%	0.0%	0.0%	1.3%
		Exhaust CH4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Total GHGs (CO2eq)	1.1%	0.0%	0.0%	0.0%	0.0%	1.0%
Alternative	50%	Exhaust VOC	32.3%	0.0%	0.0%	0.5%	1.8%	30.6%
		Evaporative VOC	40.9%	0.0%	0.0%	0.0%	0.0%	40.1%
		Total VOC	36.2%	0.0%	0.0%	0.5%	1.8%	34.9%
		Exhaust CO	17.9%	0.0%	0.0%	0.0%	0.0%	17.7%
		Exhaust NOx	21.1%	0.0%	0.0%	0.4%	0.5%	17.8%
		Exhaust PM2.5	0.0%	0.0%	0.0%	1.2%	2.4%	0.7%
		Tire/Brake PM2.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust SO2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust NH3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust CO2	1.2%	0.0%	0.0%	0.0%	0.0%	1.1%
		Exhaust N20	1.3%	0.0%	0.0%	0.0%	0.0%	1.3%
		Exhaust CH4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Total GHGs (CO2eq)	1.2%	0.0%	0.0%	0.0%	0.0%	1.1%

Lower Fraser Valley, I/M Program Benefit (%)
Relative to Modified No I/M Case, Calendar Year = 2015
Class 2b Included in Light-Duty Totals, Total GHGs = CO2+N2O+CH4

I/M Case	% GLL Inclusion	Species	Vehicle Class LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
Current	100%	Exhaust VOC	45.6%	0.0%	0.0%	0.5%	1.8%	43.6%
		Evaporative VOC	3.7%	0.0%	0.0%	0.0%	0.0%	3.7%
		Total VOC	28.7%	0.0%	0.0%	0.5%	1.8%	27.8%
		Exhaust CO	27.9%	0.0%	0.0%	0.0%	0.0%	27.7%
		Exhaust NOx	32.2%	0.0%	0.0%	0.4%	0.5%	27.8%
		Exhaust PM2.5	0.0%	0.0%	0.0%	1.2%	2.4%	0.7%
		Tire/Brake PM2.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust SO2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust NH3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust CO2	1.1%	0.0%	0.0%	0.0%	0.0%	1.0%
		Exhaust N20	1.3%	0.0%	0.0%	0.0%	0.0%	1.3%
		Exhaust CH4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Total GHGs (CO2eq)	1.1%	0.0%	0.0%	0.0%	0.0%	1.0%
Alternative	50%	Exhaust VOC	46.8%	0.0%	0.0%	0.5%	1.8%	44.8%
		Evaporative VOC	40.9%	0.0%	0.0%	0.0%	0.0%	40.1%
		Total VOC	44.4%	0.0%	0.0%	0.5%	1.8%	42.9%
		Exhaust CO	28.6%	0.0%	0.0%	0.0%	0.0%	28.4%
		Exhaust NOx	33.2%	0.0%	0.0%	0.4%	0.5%	28.7%
		Exhaust PM2.5	0.0%	0.0%	0.0%	1.2%	2.4%	0.7%
		Tire/Brake PM2.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust SO2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust NH3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust CO2	1.2%	0.0%	0.0%	0.0%	0.0%	1.1%
		Exhaust N20	1.3%	0.0%	0.0%	0.0%	0.0%	1.3%
		Exhaust CH4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Total GHGs (CO2eq)	1.2%	0.0%	0.0%	0.0%	0.0%	1.1%

Lower Fraser Valley, Emission Inventory (Tonnes per Year), Calendar Year = 2020

Class 2b Included in Light-Duty Totals, Total GHGs = CO2+N2O+CH4

I/M Case	% GLL Inclusion	Species	Vehicle Class					
			LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
None, MOBILE No I/M Baseline	100%	Exhaust VOC	4,263	8	120	19	96	4,507
		Evaporative VOC	2,732	25	31	0	0	2,788
		Total VOC	6,995	33	151	19	96	7,295
		Exhaust CO	157,183	342	1,433	41	203	159,202
		Exhaust NOx	6,430	54	66	72	759	7,381
		Exhaust PM2.5	57.4	0.6	1.1	2.4	14.5	76.0
		Tire/Brake PM2.5	72.3	0.1	0.4	0.5	1.9	75.3
		Exhaust SO2	119.2	0.5	0.3	0.7	5.3	126.0
		Exhaust NH3	1,376.2	1.3	0.9	1.9	9.8	1,390.1
		Exhaust CO2	5,086,807	29,940	13,760	67,887	568,711	5,767,104
		Exhaust N20	146	1	0	1	5	152
		Exhaust CH4	358	1	15	0	6	380
		Total GHGs (CO2eq)	5,197,035	30,171	18,139	68,029	570,729	5,884,103
None, Modified No I/M Baseline	100%	Exhaust VOC	5,869	8	120	19	96	6,112
		Evaporative VOC	2,732	25	31	0	0	2,788
		Total VOC	8,600	33	151	19	96	8,900
		Exhaust CO	187,791	342	1,433	41	203	189,810
		Exhaust NOx	8,372	54	66	72	759	9,322
		Exhaust PM2.5	57.4	0.6	1.1	2.4	14.5	76.0
		Tire/Brake PM2.5	72.3	0.1	0.4	0.5	1.9	75.3
		Exhaust SO2	119.2	0.5	0.3	0.7	5.3	126.0
		Exhaust NH3	1,376.2	1.3	0.9	1.9	9.8	1,390.1
		Exhaust CO2	5,086,807	29,940	13,760	67,887	568,711	5,767,104
		Exhaust N20	146	1	0	1	5	152
		Exhaust CH4	358	1	15	0	6	380
		Total GHGs (CO2eq)	5,197,035	30,171	18,139	68,029	570,729	5,884,103
Current	100%	Exhaust VOC	2,657	8	120	19	94	2,899
		Evaporative VOC	2,551	25	31	0	0	2,607
		Total VOC	5,208	33	151	19	94	5,505
		Exhaust CO	126,527	342	1,433	41	203	128,546
		Exhaust NOx	4,489	54	66	71	756	5,435
		Exhaust PM2.5	57.4	0.6	1.1	2.4	14.1	75.7
		Tire/Brake PM2.5	72.3	0.1	0.4	0.5	1.9	75.3
		Exhaust SO2	119.2	0.5	0.3	0.7	5.3	126.0
		Exhaust NH3	1,376.2	1.3	0.9	1.9	9.8	1,390.1
		Exhaust CO2	5,032,427	29,940	13,760	67,887	568,711	5,712,724
		Exhaust N20	146	1	0	1	5	152
		Exhaust CH4	358	1	15	0	6	380
		Total GHGs (CO2eq)	5,142,649	30,171	18,139	68,029	570,729	5,829,717

Lower Fraser Valley, Emission Inventory (Tonnes per Year), Calendar Year = 2020

Class 2b Included in Light-Duty Totals, Total GHGs = CO2+N2O+CH4

I/M Case	% GLL Inclusion	Species	Vehicle Class					
			LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
Alternative	50%	Exhaust VOC	2,569	8	120	19	94	2,811
		Evaporative VOC	1,551	25	31	0	0	1,607
		Total VOC	4,120	33	151	19	94	4,417
		Exhaust CO	125,057	342	1,433	41	203	127,076
		Exhaust NOx	4,375	54	66	71	756	5,321
		Exhaust PM2.5	57.4	0.6	1.1	2.4	14.1	75.7
		Tire/Brake PM2.5	72.3	0.1	0.4	0.5	1.9	75.3
		Exhaust SO2	119.2	0.5	0.3	0.7	5.3	126.0
		Exhaust NH3	1,376.2	1.3	0.9	1.9	9.8	1,390.1
		Exhaust CO2	5,028,799	29,940	13,760	67,887	568,711	5,709,096
		Exhaust N20	146	1	0	1	5	152
		Exhaust CH4	358	1	15	0	6	380
		Total GHGs (CO2eq)	5,139,022	30,171	18,139	68,029	570,729	5,826,090

Lower Fraser Valley, I/M Program Benefit (Tonnes per Year)
Relative to MOBILE No I/M Case, Calendar Year = 2020
Class 2b Included in Light-Duty Totals, Total GHGs = CO2+N2O+CH4

I/M Case	% GLL Inclusion	Species	Vehicle Class LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
Current	100%	Exhaust VOC	1,607	0	0	0	2	1,608
		Evaporative VOC	181	0	0	0	0	181
		Total VOC	1,787	0	0	0	2	1,789
		Exhaust CO	30,657	0	0	0	0	30,657
		Exhaust NOx	1,942	0	0	0	4	1,946
		Exhaust PM2.5	0.0	0.0	0.0	0.0	0.3	0.4
		Tire/Brake PM2.5	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust SO2	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust NH3	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust CO2	54,380	0	0	0	0	54,380
		Exhaust N20	0	0	0	0	0	0
		Exhaust CH4	0	0	0	0	0	0
		Total GHGs (CO2eq)	54,386	0	0	0	0	54,386
Alternative	50%	Exhaust VOC	1,695	0	0	0	2	1,696
		Evaporative VOC	1,181	0	0	0	0	1,181
		Total VOC	2,876	0	0	0	2	2,877
		Exhaust CO	32,126	0	0	0	0	32,126
		Exhaust NOx	2,055	0	0	0	4	2,059
		Exhaust PM2.5	0.0	0.0	0.0	0.0	0.3	0.4
		Tire/Brake PM2.5	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust SO2	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust NH3	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust CO2	58,008	0	0	0	0	58,008
		Exhaust N20	0	0	0	0	0	0
		Exhaust CH4	0	0	0	0	0	0
		Total GHGs (CO2eq)	58,013	0	0	0	0	58,013

Lower Fraser Valley, I/M Program Benefit (Tonnes per Year)
Relative to Modified No I/M Case, Calendar Year = 2020
Class 2b Included in Light-Duty Totals, Total GHGs = CO2+N2O+CH4

I/M Case	% GLL Inclusion	Species	Vehicle Class LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
Current	100%	Exhaust VOC	3,212	0	0	0	2	3,213
		Evaporative VOC	181	0	0	0	0	181
		Total VOC	3,393	0	0	0	2	3,394
		Exhaust CO	61,264	0	0	0	0	61,264
		Exhaust NOx	3,883	0	0	0	4	3,887
		Exhaust PM2.5	0.0	0.0	0.0	0.0	0.3	0.4
		Tire/Brake PM2.5	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust SO2	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust NH3	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust CO2	54,380	0	0	0	0	54,380
		Exhaust N20	0	0	0	0	0	0
		Exhaust CH4	0	0	0	0	0	0
		Total GHGs (CO2eq)	54,386	0	0	0	0	54,386
Alternative	50%	Exhaust VOC	3,300	0	0	0	2	3,302
		Evaporative VOC	1,181	0	0	0	0	1,181
		Total VOC	4,481	0	0	0	2	4,483
		Exhaust CO	62,734	0	0	0	0	62,734
		Exhaust NOx	3,997	0	0	0	4	4,001
		Exhaust PM2.5	0.0	0.0	0.0	0.0	0.3	0.4
		Tire/Brake PM2.5	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust SO2	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust NH3	0.0	0.0	0.0	0.0	0.0	0.0
		Exhaust CO2	58,008	0	0	0	0	58,008
		Exhaust N20	0	0	0	0	0	0
		Exhaust CH4	0	0	0	0	0	0
		Total GHGs (CO2eq)	58,013	0	0	0	0	58,013

Lower Fraser Valley, I/M Program Benefit (%)
Relative to MOBILE No I/M Case, Calendar Year = 2020
Class 2b Included in Light-Duty Totals, Total GHGs = CO2+N2O+CH4

I/M Case	% GLL Inclusion	Species	Vehicle Class					
			LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
Current	100%	Exhaust VOC	37.7%	0.0%	0.0%	0.6%	1.7%	35.7%
		Evaporative VOC	6.6%	0.0%	0.0%	0.0%	0.0%	6.5%
		Total VOC	25.6%	0.0%	0.0%	0.6%	1.7%	24.5%
		Exhaust CO	19.5%	0.0%	0.0%	0.0%	0.0%	19.3%
		Exhaust NOx	30.2%	0.0%	0.0%	0.4%	0.5%	26.4%
		Exhaust PM2.5	0.0%	0.0%	0.0%	1.3%	2.3%	0.5%
		Tire/Brake PM2.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust SO2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust NH3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust CO2	1.1%	0.0%	0.0%	0.0%	0.0%	0.9%
		Exhaust N20	0.1%	0.0%	0.0%	0.0%	0.0%	0.1%
		Exhaust CH4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Total GHGs (CO2eq)	1.0%	0.0%	0.0%	0.0%	0.0%	0.9%
Alternative	50%	Exhaust VOC	39.7%	0.0%	0.0%	0.6%	1.7%	37.6%
		Evaporative VOC	43.2%	0.0%	0.0%	0.0%	0.0%	42.4%
		Total VOC	41.1%	0.0%	0.0%	0.6%	1.7%	39.4%
		Exhaust CO	20.4%	0.0%	0.0%	0.0%	0.0%	20.2%
		Exhaust NOx	32.0%	0.0%	0.0%	0.4%	0.5%	27.9%
		Exhaust PM2.5	0.0%	0.0%	0.0%	1.3%	2.3%	0.5%
		Tire/Brake PM2.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust SO2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust NH3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust CO2	1.1%	0.0%	0.0%	0.0%	0.0%	1.0%
		Exhaust N20	0.1%	0.0%	0.0%	0.0%	0.0%	0.1%
		Exhaust CH4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Total GHGs (CO2eq)	1.1%	0.0%	0.0%	0.0%	0.0%	1.0%

Lower Fraser Valley, I/M Program Benefit (%)
Relative to Modified No I/M Case, Calendar Year = 2020
Class 2b Included in Light-Duty Totals, Total GHGs = CO2+N2O+CH4

I/M Case	% GLL Inclusion	Species	Vehicle Class LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
Current	100%	Exhaust VOC	54.7%	0.0%	0.0%	0.6%	1.7%	52.6%
		Evaporative VOC	6.6%	0.0%	0.0%	0.0%	0.0%	6.5%
		Total VOC	39.4%	0.0%	0.0%	0.6%	1.7%	38.1%
		Exhaust CO	32.6%	0.0%	0.0%	0.0%	0.0%	32.3%
		Exhaust NOx	46.4%	0.0%	0.0%	0.4%	0.5%	41.7%
		Exhaust PM2.5	0.0%	0.0%	0.0%	1.3%	2.3%	0.5%
		Tire/Brake PM2.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust SO2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust NH3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust CO2	1.1%	0.0%	0.0%	0.0%	0.0%	0.9%
		Exhaust N20	0.1%	0.0%	0.0%	0.0%	0.0%	0.1%
		Exhaust CH4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Total GHGs (CO2eq)	1.0%	0.0%	0.0%	0.0%	0.0%	0.9%
Alternative	50%	Exhaust VOC	56.2%	0.0%	0.0%	0.6%	1.7%	54.0%
		Evaporative VOC	43.2%	0.0%	0.0%	0.0%	0.0%	42.4%
		Total VOC	52.1%	0.0%	0.0%	0.6%	1.7%	50.4%
		Exhaust CO	33.4%	0.0%	0.0%	0.0%	0.0%	33.1%
		Exhaust NOx	47.7%	0.0%	0.0%	0.4%	0.5%	42.9%
		Exhaust PM2.5	0.0%	0.0%	0.0%	1.3%	2.3%	0.5%
		Tire/Brake PM2.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust SO2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust NH3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Exhaust CO2	1.1%	0.0%	0.0%	0.0%	0.0%	1.0%
		Exhaust N20	0.1%	0.0%	0.0%	0.0%	0.0%	0.1%
		Exhaust CH4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Total GHGs (CO2eq)	1.1%	0.0%	0.0%	0.0%	0.0%	1.0%

Lower Fraser Valley, Emission Inventory (Tonnes per Year), Calendar Year = 2020

Class 2b Included in Light-Duty Totals

I/M Case	% GLL Inclusion	Species	Vehicle Class					
			LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
None, MOBILE No I/M Baseline	100%	Exhaust Benzene	230.97	0.34	3.43	0.32	1.06	236.11
		Evaporative Benzene	14.76	0.14	0.18	0.00	0.00	15.07
		Total Benzene	245.73	0.48	3.61	0.32	1.06	251.19
		Exhaust Acetaldehyde	24.65	0.05	0.93	0.37	2.90	28.89
		Exhaust Acrolein	2.91	0.01	0.09	0.07	0.35	3.43
		Exhaust Butadiene	30.24	0.03	1.37	0.15	0.61	32.40
		Exhaust Formaldehyde	65.17	0.17	3.33	1.06	7.87	77.59
None, Modified No I/M Baseline	100%	Exhaust Benzene	317.93	0.34	3.43	0.32	1.06	323.07
		Evaporative Benzene	14.76	0.14	0.18	0.00	0.00	15.07
		Total Benzene	332.69	0.48	3.61	0.32	1.06	338.15
		Exhaust Acetaldehyde	29.45	0.05	0.93	0.37	2.90	33.69
		Exhaust Acrolein	3.79	0.01	0.09	0.07	0.35	4.31
		Exhaust Butadiene	30.24	0.03	1.37	0.15	0.61	32.40
		Exhaust Formaldehyde	65.17	0.17	3.33	1.06	7.87	77.59
Current	100%	Exhaust Benzene	143.35	0.34	3.43	0.32	1.04	148.48
		Evaporative Benzene	13.74	0.14	0.18	0.00	0.00	14.05
		Total Benzene	157.09	0.48	3.61	0.32	1.04	162.53
		Exhaust Acetaldehyde	15.43	0.05	0.93	0.36	2.85	19.61
		Exhaust Acrolein	1.81	0.01	0.09	0.07	0.35	2.33
		Exhaust Butadiene	18.44	0.03	1.37	0.15	0.60	20.60
		Exhaust Formaldehyde	40.97	0.17	3.33	1.05	7.74	53.25
Alternative	50%	Exhaust Benzene	138.61	0.34	3.43	0.32	1.04	143.73
		Evaporative Benzene	8.35	0.14	0.18	0.00	0.00	8.67
		Total Benzene	146.96	0.48	3.61	0.32	1.04	152.40
		Exhaust Acetaldehyde	14.91	0.05	0.93	0.36	2.85	19.10
		Exhaust Acrolein	1.75	0.01	0.09	0.07	0.35	2.27
		Exhaust Butadiene	17.84	0.03	1.37	0.15	0.60	19.99
		Exhaust Formaldehyde	39.61	0.17	3.33	1.05	7.74	51.89

Lower Fraser Valley, I/M Program Benefit (Tonnes per Year)
Relative to MOBILE No I/M Case, Calendar Year = 2020
Class 2b Included in Light-Duty Totals

I/M Case	% GLL Inclusion	Species	Vehicle Class LD Gasoline	 HD Gasoline	 MC	 LD Diesel	 HD Diesel	 Total
Current	100%	Exhaust Benzene	87.62	0.00	0.00	0.00	0.02	87.64
		Evaporative Benzene	1.02	0.00	0.00	0.00	0.00	1.02
		Total Benzene	88.64	0.00	0.00	0.00	0.02	88.66
		Exhaust Acetaldehyde	9.22	0.00	0.00	0.00	0.05	9.28
		Exhaust Acrolein	1.10	0.00	0.00	0.00	0.01	1.11
		Exhaust Butadiene	11.79	0.00	0.00	0.00	0.01	11.80
		Exhaust Formaldehyde	24.20	0.00	0.00	0.01	0.13	24.34
Alternative	50%	Exhaust Benzene	92.36	0.00	0.00	0.00	0.02	92.38
		Evaporative Benzene	6.41	0.00	0.00	0.00	0.00	6.41
		Total Benzene	98.77	0.00	0.00	0.00	0.02	98.79
		Exhaust Acetaldehyde	9.73	0.00	0.00	0.00	0.05	9.79
		Exhaust Acrolein	1.16	0.00	0.00	0.00	0.01	1.17
		Exhaust Butadiene	12.40	0.00	0.00	0.00	0.01	12.41
		Exhaust Formaldehyde	25.56	0.00	0.00	0.01	0.13	25.71

Lower Fraser Valley, I/M Program Benefit (Tonnes per Year)
Relative to Modified No I/M Case, Calendar Year = 2020
Class 2b Included in Light-Duty Totals

I/M Case	% GLL Inclusion	Species	Vehicle Class LD Gasoline	 HD Gasoline	 MC	 LD Diesel	 HD Diesel	 Total
Current	100%	Exhaust Benzene	174.58	0.00	0.00	0.00	0.02	174.60
		Evaporative Benzene	1.02	0.00	0.00	0.00	0.00	1.02
		Total Benzene	175.60	0.00	0.00	0.00	0.02	175.62
		Exhaust Acetaldehyde	14.02	0.00	0.00	0.00	0.05	14.07
		Exhaust Acrolein	1.98	0.00	0.00	0.00	0.01	1.98
		Exhaust Butadiene	11.79	0.00	0.00	0.00	0.01	11.80
		Exhaust Formaldehyde	24.20	0.00	0.00	0.01	0.13	24.34
Alternative	50%	Exhaust Benzene	179.32	0.00	0.00	0.00	0.02	179.34
		Evaporative Benzene	6.41	0.00	0.00	0.00	0.00	6.41
		Total Benzene	185.73	0.00	0.00	0.00	0.02	185.75
		Exhaust Acetaldehyde	14.53	0.00	0.00	0.00	0.05	14.59
		Exhaust Acrolein	2.04	0.00	0.00	0.00	0.01	2.04
		Exhaust Butadiene	12.40	0.00	0.00	0.00	0.01	12.41
		Exhaust Formaldehyde	25.56	0.00	0.00	0.01	0.13	25.71

Lower Fraser Valley, I/M Program Benefit (%)
Relative to MOBILE No I/M Case, Calendar Year = 2020
Class 2b Included in Light-Duty Totals

I/M Case	% GLL Inclusion	Species	Vehicle Class LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
Current	100%	Exhaust Benzene	37.9%	0.0%	0.0%	0.4%	1.7%	37.1%
		Evaporative Benzene	6.9%	0.0%	0.0%	0.0%	0.0%	6.8%
		Total Benzene	36.1%	0.0%	0.0%	0.4%	1.7%	35.3%
		Exhaust Acetaldehyde	37.4%	0.0%	0.0%	1.0%	1.7%	32.1%
		Exhaust Acrolein	37.7%	0.0%	0.0%	0.7%	1.7%	32.2%
		Exhaust Butadiene	39.0%	0.0%	0.0%	0.5%	1.7%	36.4%
		Exhaust Formaldehyde	37.1%	0.0%	0.0%	1.0%	1.7%	31.4%
Alternative	50%	Exhaust Benzene	40.0%	0.0%	0.0%	0.4%	1.7%	39.1%
		Evaporative Benzene	43.4%	0.0%	0.0%	0.0%	0.0%	42.5%
		Total Benzene	40.2%	0.0%	0.0%	0.4%	1.7%	39.3%
		Exhaust Acetaldehyde	39.5%	0.0%	0.0%	1.0%	1.7%	33.9%
		Exhaust Acrolein	39.8%	0.0%	0.0%	0.7%	1.7%	34.0%
		Exhaust Butadiene	41.0%	0.0%	0.0%	0.5%	1.7%	38.3%
		Exhaust Formaldehyde	39.2%	0.0%	0.0%	1.0%	1.7%	33.1%

Lower Fraser Valley, I/M Program Benefit (%)
Relative to Modified No I/M Case, Calendar Year = 2020
Class 2b Included in Light-Duty Totals

I/M Case	% GLL Inclusion	Species	Vehicle Class LD Gasoline	HD Gasoline	MC	LD Diesel	HD Diesel	Total
Current	100%	Exhaust Benzene	54.9%	0.0%	0.0%	0.4%	1.7%	54.0%
		Evaporative Benzene	6.9%	0.0%	0.0%	0.0%	0.0%	6.8%
		Total Benzene	52.8%	0.0%	0.0%	0.4%	1.7%	51.9%
		Exhaust Acetaldehyde	47.6%	0.0%	0.0%	1.0%	1.7%	41.8%
		Exhaust Acrolein	52.2%	0.0%	0.0%	0.7%	1.7%	46.0%
		Exhaust Butadiene	39.0%	0.0%	0.0%	0.5%	1.7%	36.4%
		Exhaust Formaldehyde	37.1%	0.0%	0.0%	1.0%	1.7%	31.4%
Alternative	50%	Exhaust Benzene	56.4%	0.0%	0.0%	0.4%	1.7%	55.5%
		Evaporative Benzene	43.4%	0.0%	0.0%	0.0%	0.0%	42.5%
		Total Benzene	55.8%	0.0%	0.0%	0.4%	1.7%	54.9%
		Exhaust Acetaldehyde	49.4%	0.0%	0.0%	1.0%	1.7%	43.3%
		Exhaust Acrolein	53.8%	0.0%	0.0%	0.7%	1.7%	47.4%
		Exhaust Butadiene	41.0%	0.0%	0.0%	0.5%	1.7%	38.3%
		Exhaust Formaldehyde	39.2%	0.0%	0.0%	1.0%	1.7%	33.1%